PPU College Of Engineering and Technology

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Electrical and Computer Engineering Department

Communication and Electronic Engineering

Bachelor Thesis

Graduation Project

LTE Versus WiMAX In Terms Of Coverage And Quality Of Service In Hebron City

Project team

Afnan Asafrah

Lina Al Mohtaseb

Project supervisor

Dr. Khaled Hijjeh

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كلية الهندسة و التكنولوجيا

دائرة الهندسة الكهربائية و الحاسوب

هندسة اتصالات و إلكترونيات

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LTE Versus WiMAX In Terms Of Coverage
And Quality Of Service In Hebron City

أسماء الطلبة:

أفنان عصافرة

لينا المحتسب

بناءً على نظام كلية الهندسة و التكنولوجيا و إشراف و متابعة المشرف المباشر على المشروع و موافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية و الحاسوب و ذلك استكمالاً لمتطلبات درجة البكالوريوس في تخصص هندسة الاتصالات و الالكترونيات.

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ملخص

تعتبر الحواسيب وشبكاتها رائدة الثورة التكنولوجية في عالمنا اليوم ، ووفقاً للتطور المتسارع على هذه الأجهزة فإننا نلاحظ ظهور تكنولوجيات جديدة كل يوم . ولذلك أصبح من الصعوبة بمكان على مزودي خدمات الانترنت والشبكات اللاسلكية أن يتخذوا قراراً حاسماً فيما يتعلق بالتكنولوجيا التي سيعتمدونها في تقديم الخدمات للمشتركين ، لأن هدفهم هو تقديم أفضل خدمة واستقطاب أكبر عدد ممكن من المشتركين. و بذلك فإن المنافسة بين مزودي الخدمة تزداد يوماً بعد آخر ، فكل منهم يحاول إقناع المشتركين بالانضمام لخدمته . أما على صعيد المستخدم فهو يسعى لاختيار التكنولوجيا التي تحقق له الخدمة الأوفر والأفضل والأكثر كفاءة.

قد جاء هذا المشروع ليقوم بتنفيذ مقارنة بين اثنتين من تكنولوجيا الشبكات اللاسلكية وهما (LTE) من جهة و (WIMAX) من الجهة الأخرى. حيث سيتم التطرق إلى ميزات كل منهما وسلبياته ، كذلك فإنه سيتم إعداد تخطيط لمدينة الخليل لكل منهما، حتى يتم التوصل إلى نتيجة تبين أي منهما هي الأفضل لمدينة الخليل ، وسيتم إجراء تعديلات وتحسينات على عوامل ال (LTE)وأخيراً تقديم مقارنة متكاملة بين هاتين التقنيتين.

Contents

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Tables

List of abbreviations

A

AWGN: Additive White Gaussian Noise

AMC: Adaptive Modulation and Coding

AP: Access Point

B

BER: Bit Error Rate

BS: Base Station

C

CN: Core Network

CS: Convergence Sublayer

CPS: Common Part Sublayer

C/I: Carrier To Interference

D

DSP: Digital Signal Processing

DSL: Digital Subscriber Line

E

EPC: Evolved Packet Core

E-UTRAN: Evolved-Universal Terrestrial Radio Access Network

eNB: eNodeB

ETSI HIPERMAN: European Telecommunications standards Institute High Performance Radio Metropolitan Area Network

EDGE: Enhanced Data for GSM Evolution

F

FDD: Frequency Division Duplexing

G

GSM: Global System for Mobile

3GPP: 3rd Generation Partnership Project

3G: Third Generation

4G: Fourth Generation

1G: First Generation

2G: Second Generation

GPRS: General Packet Radio Service

H

HSPA: High Speed Packet Access

I

IP: Internet Protocol

IEEE: Institute of Electrical and Electronics Engineers

IMT: International Mobile Telecommunications

ISI: Inter Symbol Interference

L

LTE: Long Term Evolution

LOS: Line Of Sight

M

MME: Mobility Management Entity

MAC: Media Access Control

MIMO: Multi Input, Multi Output

N

NAS: Non Access Stratum

O

OFDMA: Orthogonal Frequency Division Multiple Access

OFDM: Orthogonal Frequency Division Multiplexing

P

PDCP: Packet Data Convergence Protocol

PHY: Physical Layer

PCMCIA: Personal Computer Memory Card International Association

PAN: Personal Area Network

PTP: Point To Point

PTM: Point To Multipoint

Q

QoS: Quality Of Service

R

RRC: Radio Resource Control

RLC: Radio Link Control

RS: Repeater Station

S

SUI: Stanford University Interim

SAS: Smart Antenna System

SC-FDMA: Single Carrier-Frequency Division Multiple Access

SISO: Single Input, Single Output

SNR: Signal to Noise Ratio

SS: Subscriber Station

SINR: Signal to Interference and Noise Ratio

T

TDD: Time Division Duplexing

U

UMTS: Universal Mobile Telecommunications System

UE: User Equipment

UGS: Unsolicited Grant Service

V

VoIP: Voice Over Internet Protocol

W

WiMAX: Worldwide Interoperability for Microwave Access

WiFi: Wireless Fidelity

WLAN: Wireless Local Area Network

WiBRO: Wireless Broadband

Chapter 1

Introduction

Contents

1.1.Overview

Network is a group of two or more nodes communicating together directly or indirectly. These nodes may be computers, printers, cameras, mobile phones and laptops. There are two types of networks; depending on the connecting medium, wired and wireless network. People in all over the world tend toward wireless technologies and networks where less wires are used, so less mess. Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) are wireless networks providing data and Voice Over Internet Protocol (VoIP) service.

1.2.General Project Idea

LTE and WiMAX each one has its own advantages and disadvantages. Wireless network providers choose the type of their network either LTE or WiMAX after studying their advantages and disadvantages depending of users needs.

Provider and user are interested in some important communication's parameters. These parameters are coverage, capacity and quality of service. Coverage is a parameter that points to the covered area size. Capacity is the amount of data transferred or received in time unit(data rate). Quality of service could be evaluated through carrier to interference value. User desires high coverage, high carrier to interference value (low interference). So a good plan should be done to the LTE and WiMAX networks.

1.3.Technologies Overview

Here is a brief overview about these both technologies:

1.3.1.LTE Network

LTE is a wireless communication network of high speed data for mobile phones and data terminals, it is an evolution to the Global System for Mobile (GSM)/ Universal Mobile Telecommunications System (UMTS) standards, it is developing by the 3rd Generation Partnership Project (3GPP). The first appearance of LTE service was being in 2009. Its goal was to increase the data capacity using different Digital Signal Processing (DSP) and modulation types than that used in Third Generation (3G) networks. It is an Internet Protocol (IP) based network with lower transfer latency.[(1)(2)]

Figure 1.1. LTE logo

LTE operates on different frequency bands, it operates on 800, 900, 1800, 2100, 2600 MHz and other bands. The operating frequency band differs between countries, so users need multi band capable phones for international roaming. LTE covers cells of radius ranges from tens of meters up to 100 Km and supports data rate up to 300 Mbps.[(1)(2)]

1.3.2.WiMAX Network

WiMAX was created by WiMAX Forum. It is a broadband wireless network based on Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard, it depends on using base stations to provide the service and it operates in 2 - 66 GHz radio bands.[(3)]

Figure1.2.WiMAX logo

WiMAX networks are classified into two categories. One of them is for fixed WiMAX called 802.16d and the other for mobile WiMAX called 802.16e. They are suitable alternatives for Digital Subscriber Line (DSL) and providing wireless internet service for last mile.(3)

WiMAX reaches a range up to 50 Km for fixed stations and a range of 5 – 15 Km for mobile stations with data rate up to 1 Gbps for fixed stations. It can provide a mobile broadband connection as cell phone networks. But at large range, Bit Error Rate (BER) increases.(3)

1.4.Motivations

providers have to decide which of these technologies can serve better, LTE or WiMAX; depending to the users requirements. Also the service providers aim to provide the highest number of users with the best service quality. Coverage and quality are important points all users face them in any wireless network.

So, this project aim is to perform a study of LTE and WiMAX in terms of coverage and quality of service and makes improvement for them.

1.5.Problem Statement

Nowadays it is essential to connect and share data wherever user exists. That is why wireless networks is considered as important field of research which changes rapidly; new technologies appear from time to time. As known, the trend of people now is towards wireless networks because they provide good bandwidth and save money and space as it does not need wires.

In wireless networks there are several technologies as LTE and WiMAX. They are two popular technologies which are widely used all over the world. They differ in their coverage and quality. Choosing one of them to build a network needs a comprehensive comparison to decide which technology is more suitable depending on the needs of the intended network and the nature of the area.

This research aims to carry out a comparison between LTE and WiMAX in terms of their quality and coverage to decide which of them is more suitable to build a network that covers the city of Hebron.

1.6.Project Objectives

Project objectives are concluded in:

1. Make a plan for Hebron City using both LTE and WiMAX technologies.
2. Make an improvement on the coverage and the quality of service for both technologies.
3. Do a comparison between LTE and WiMAX.

This plan is going to study the coverage and quality of service for LTE and WiMAX networks. We will use Jawwal's Company software. First, we aim to be familiar of how the software works using its guide tool, then we will start planning for both technologies. After that we will go for ground survey for some sites.

Then an improvement on LTE and WiMAX coverage and quality of service will be done. Finally, making comparison between LTE and WiMAX.

1.7.Needed Technology

In order to achieve a fair comparison between LTE and WIMAX, a plan for both technologies must be carried out in Hebron City using network planning simulation tool called Mentum Planet Tool. Also, a GPS tool is important for the field survey to determine the position of some sites.

1.8.Project Idea (Approach)

LTE and WiMAX both are wireless communication techniques. Each one has its own advantages and disadvantages. Providers are interested in some important wireless communication parameters. Coverage is one of that parameters, it is important for the user to find LTE or WiMAX available everywhere. Carrier to interference value shows how much is the wireless technique reliable. The effect of carrier to interference value differs from data type to another, but generally we need to reach high carrier to interference value as possible as we can to get desirable high quality.

We are going to make an initial plan of LTE and WiMAX for Hebron city by using Jawwal Company planning tools. Enhancing will be made on this plan according to coverage and quality parameters. After that we will make a comparison between LTE and WiMAX in terms of coverage and quality.

The following flowchart illustrates the steps that will be followed to achieve the LTE and WiMAX plans in Hebron City.

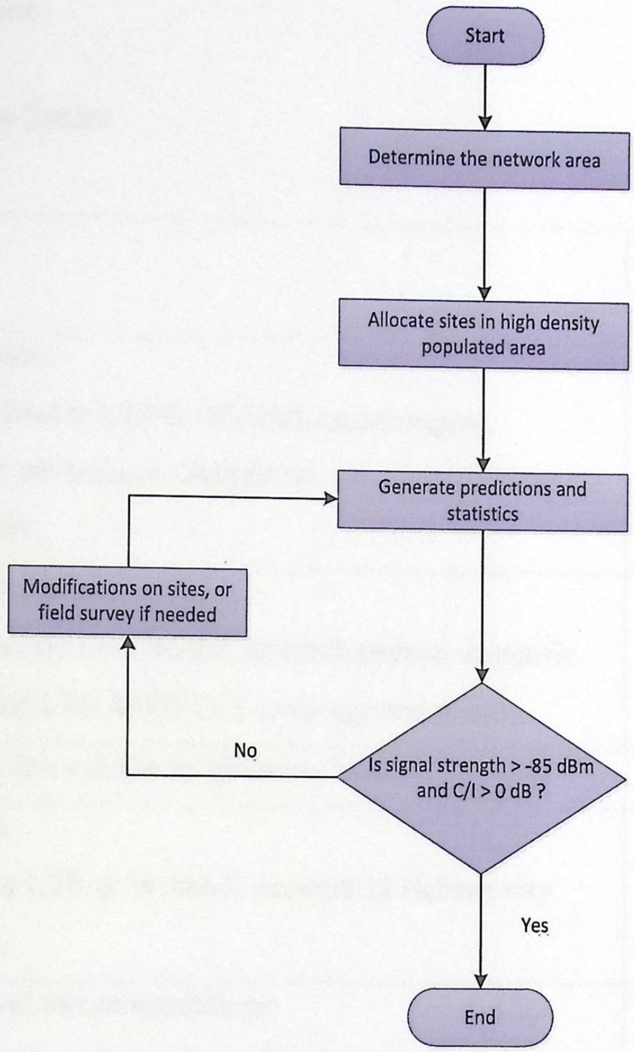


Figure 1.3.Initial planning steps flowchart.

1.9.Deliverables

Finally, we expect to have these results:

1. Results for the comparison between LTE and WiMAX that will lead us to decide which technology is more suitable to cover Hebron city.
2. Comprehensive LTE and WiMAX plan for Hebron city.

1.10. Project Time Frame

Table 1.1.project time frame:

Task	Needed time
Ch.1 Introduction. Brief explanation for LTE & WiMAX technologies, recognize their advantages, limitations, project objectives and project steps.	2 weeks.
Ch.2 Literature review. Collect information from books, research papers, scientific magazines about LTE &WiMAX coverage and quality.	4 weeks.
Understanding Jawwal theory planning tool.	1 week.
Ch3. Real plan. Make a plan for LTE & WiMAX network in Hebron city using software.	13 weeks.
Ch4. Results and recommendations. Illustrate the final results and provide some recommendations for future works.	1 week.
Closing.	1 weeks.

Chapter 2

Literature review

Contents

2.1.Overview

Wireless networks in general passed and still passing through huge number of developments. This evolution beginnings have backed to Hertz's discovery of radio waves in 1888. Followed by Marconi's first experiment of transmitting and receiving radio waves over long distance. Then radio communication and radar come to be available for military use. In 1971, ALOHANET was the first packet based wireless network created by researchers at the University of Hawaii.

2.2.LTE Technology

2.2.1.Introduction To LTE

Wireless technologies passed through many evolutions until reached Fourth Generation (4G). All these evolutions aimed to improve the performance and the efficiency in a high mobile environment. The First Generation (1G) has supported a basic mobile voice, while Second Generation (2G) has supported capacity and coverage. Then 3G has come to provide data service at higher speeds; this opens the gates to truly "mobile broadband".[(1)]

The mobile broadband refers to the internet connection that provides data, voice and video services at high speeds in mobile devices. This mobile broadband is included in the 4G. The 4G technology is an IP- Orthogonal Frequency Division Multiple Access (OFDMA) based technology. LTE is a 4G technology.[(1)]

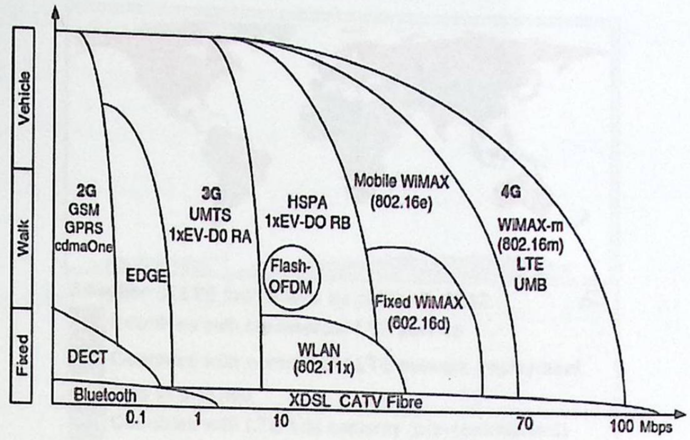


Figure 2.1. Wireless networks sequence.[(1),page6]

2.2.2.Definition

LTE is a wireless communication network of high speed data for mobile phones and data terminals. It is an evolution to the GSM/UMTS standards. It is developed by the 3GPP. Its goal is to increase the data capacity using different DSP and modulation types than that used in 3G networks. It is an IP based network with lower transfer latency.[(1)(2)]

LTE uses OFDMA for downlink and Single Carrier-Frequency Division Multiple Access (SC-FDMA) for uplink as multiple access technique under the assumption that all services would be packet switched. LTE can be deployed in both (Frequency Division Duplexing) FDD and (Time Division Duplexing) TDD, both has advantages and disadvantages. The operator decides which to use, but generally FDD is more adapted in the world. The channel bandwidth is up to 20 MHz.[(1)(2)(4)]

2.2.3.Why LTE?

The internationality of the LTE encourages providers and users to turn to LTE. Figure 2.2.shows the distribution of LTE all over the world.[(1)(2)]

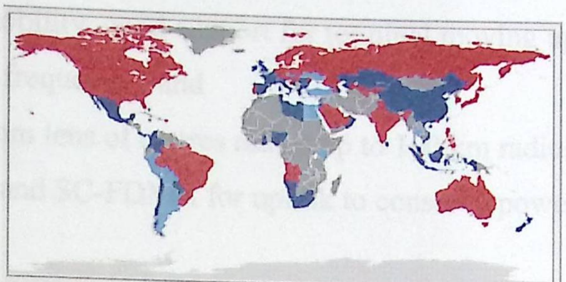


Figure 2.2. LTE distribution all over the world.(1)(2)

In December 2009,TeliaSonera at Sweden and Norway become the 1st operator in the world that offers LTE. In September 2010, a service provider in US called Metro PCs become the 2nd LTE operator which launched LTE services.(1)(2)

LTE is considered as a cost effective and efficient technology due to:

1. Flat architecture consisting of just one type of nodes, the base station, known in LTE as the eNodeB; LTE base stations can communicate to each other directly through the interface between two eNodeBs.
2. Effective protocols for the support of packet switched services.
3. Open interfaces and support of multi vendor equipment interoperability.
4. Efficient mechanisms for operation and maintenance, including self optimization functionalities.
5. Support of easy deployment and configuration, for example for so-called home base stations (otherwise known as femto cells).(2)(4)

LTE Advantages:

1. Peak download rate up to 300 Mbps and upload up to 75 Mbps.
2. Low data transfer latency and low connection setup time.

3. Improved support for mobility, good support for terminal moving up to 350 Km/h or 500 Km/h depending on the frequency band
4. Support for cell sizes from tens of metres radius up to 100 km radius.
5. OFDMA for downlink, and SC-FDMA for uplink to conserve power.[(1)(2)]

Figure 2.4.shows the time latency for some technologies including LTE:

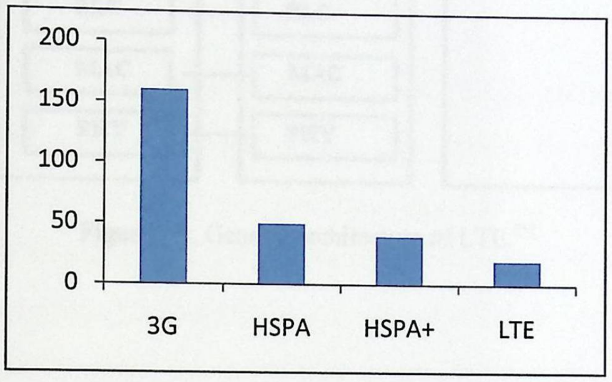


Figure 2.3.Latency(ms).[(4),page3]

2.2.4.LTE Construction

The LTE architecture contains two parts:

1. Evolved Packet Core (EPC) part: this part is responsible for authentication setup and end of connection.
2. Evolved-Universal Terrestrial Radio Access Network (E-UTRAN) part: this part is responsible for all functions that are related of interfaces.[(4)]

2.2.5.LTE General Architecture(Layers)

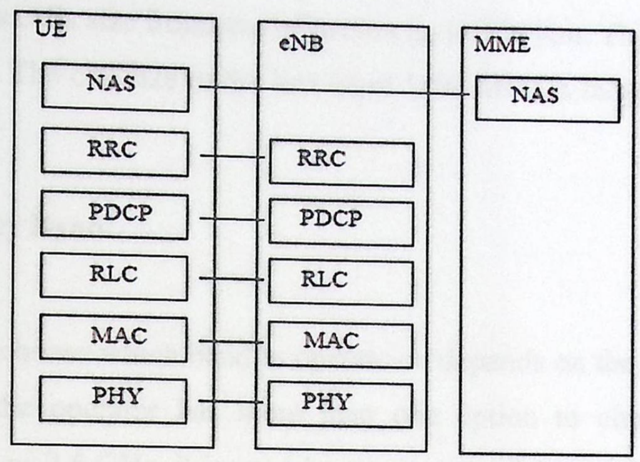


Figure 2.4. General architecture of LTE.[5]

2.2.6.LTE Versions

There are two versions of LTE:

1. LTE: The 3GPP has completed the specifications of the LTE as part of release 8. LTE offers 326 Mbps with 4*4 Multi Input, Multi Output (MIMO) and 172 Mbps with 2*2 MIMO in 20 MHz spectrum. It supports both TDD and FDD.
2. LTE Advanced: In LTE advanced, the 3GPP is addressing the requirements to satisfy the specifications of the International Mobile Telecommunications (IMT) advanced. LTE Advanced standards defined in 3GPP release 10. LTE Advanced is backward compatibility, this means that LTE Advanced devices can operate in LTE and vice versa. It supports download data rate up to 1000 Mbps for low mobility devices and up to 100 Mbps for high mobility devices.[6]

2.2.7.LTE Operating Range

LTE supports cells size from tens of meters up to 100 Km. This size depends on the operation frequency. The cell size in the low band 1800 MHz is larger than in that in high band 2600 MHz.(1)(2)

2.2.8.LTE Frequency Band

Generally to choose which band to operate on depends on the availability of such a band, but in LTE the operator has more than one option to choose from. The high frequency band such as 2.6 GHz, it is used in many parts of the world. The low frequency band such as 700 and 800 MHz, at this band signal is allowed to travel farther (cell radius may be 3 or 4 times larger than 2.6 GHz), better coverage inside buildings, so it needs less number of sites than that required to achieve the same coverage in 2.6 GHz and as a result lower cost. But in this band, there is a high level of uncertainty.(4)

Operators can also consider the option of re-farming their existing licensed frequencies, if regulation permits, to offer LTE. For example, Mobyland in Poland has launched the world's first LTE network in the 1800 MHz spectrum.(4)

2.2.9.Network Topology

LTE nodes topology:

Like any network, the nodes of LTE have certain topologies that determine the way the nodes are distributed inside the network:

1. Point to point topology: in this topology the nodes are connected to each other in a way that each of them receives data from the center i.e. from the main station or base station, also all nodes have the same priority to transmit and receive data.

2. Point to multipoint topology: this topology the nodes are connected to each other in a way that there is a main node connected to the main station, and this node receive the data from the main station then broadcast it to the nodes that are connected to this node. So this node forms a primary one, and the nodes can not communicate with the base station without this node.[2]

2.3.OFDM And MIMO Technology

2.3.1. Orthogonal Frequency Division Multiplexing (OFDM)

Orthogonal Frequency Division Multiplexing. In this technique the channel bandwidth is divided into multi subcarriers. These subcarriers are orthogonal such that overlapping is allowed without any interference occurs. Instead of using all the bandwidth channel for transmitting one symbol, here many symbols transmitted over multi different subcarriers simultaneously. This means increasing the channel efficiency. OFDM also reduce the Inter Symbol Interference (ISI).[7][8]

2.3.2.Multi Input, Multi Output (MIMO)

Multi Input, Multi Output. It is used to transmit independent data streams over multiple antennas on the transmitter side. And there are multiple antennas on the receiver side to receive these data streams. This technique is used to increase the data rate capacity compared to the Single Input, Single Output (SISO). Figure 2.6.shows a SISO system which has one transmitter and receiver antenna. And Figure 2.7.shows a MIMO system which here has two transmitter and receiver antennas.[7]

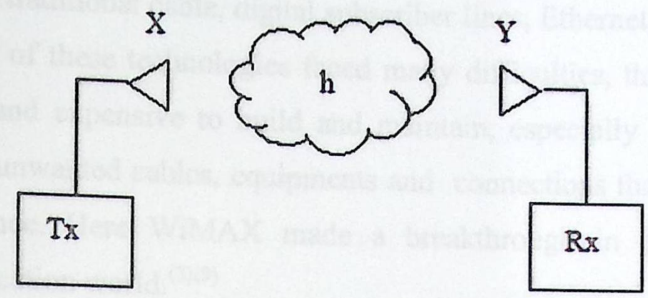


Figure 2.5. SISO system.(7),page30

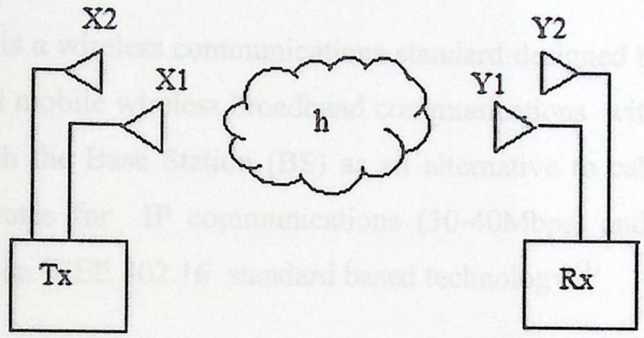


Figure 2.6. MIMO system.(7),page30

MIMO also could be used as a diversity technique by using extra receive antennas. The extra receive antennas provide improvement in Signal to Noise Ratio (SNR) especially at higher modulation and code rates . The receive antennas receive the same data stream and use it to detect the real data stream transmitted. This could help increasing the detection accuracy.[7]

OFDM and MIMO are used to improve the capacity and the Quality Of Service (QoS).

2.4.WiMAX Technology

2.4.1.Introduction To WiMAX

Historically, the user always aims to have a high speed and broadband communication service. The traditional way to achieve this was the wired access technologies such as traditional cable, digital subscriber lines, Ethernet, and fiber optic. But the implementation of these technologies faced many difficulties, these technologies are extremely difficult and expensive to build and maintain, especially in rural and remote areas. Furthermore, unwanted cables, equipments and connections that may consume size and cause disturbance. Here WiMAX made a breakthrough in the high speed and broadband communication world.[3][9]

2.4.2. Definition

WiMAX: It is a wireless communications standard designed by WiMAX Forum to provide portable and mobile wireless broadband communications with no need to the Line Of Sight (LOS) with the Base Station (BS) as an alternative to cables and DSL. It can provide high data rates for IP communications (30-40Mbps) and (1Gbps) for fixed stations. WiMAX is an IEEE 802.16 standard based technology.[3]

WiMAX Forum:

The WiMAX Forum was formed in April 2001 as a nonprofit international organization to certify conformance and interoperability of products on the basis of the IEEE 802.16 and European Telecommunications standards Institute High Performance Radio Metropolitan Area Network (ETSI HIPERMAN) standards. This forum is also heavily involved as an advocate for 802.16 technology. It has now grown to include over 420 member companies. The WiMAX Forum currently operates eight working groups: application, certification, global roaming, marketing, networking, regulatory, service provider, and technical.[3][9]

2.4.3. Why WiMAX?

WiMAX is a wireless technology; this means avoiding all the disturbances of wired technologies, because wireless systems have the capacity to address broad geographic areas without costly infrastructure development required in deploying cable links to individual sites. Also it provides an affordable wireless broadband access for all, improving quality of life which leads to economic improvement.(3)

Another reason of why it is reasonable to choose WiMAX is the high coverage it provides. It provides up to 50 km service range which allows users to have a broadband connection with no need to LOS with the BS, this means providing the service to uncovered customers in the DSL or cables range, with high QoS in both real-time applications (delay sensitive VOIP and delay streaming video) and non real time downloads.(3)

WiMAX Advantages:

1. It provides interoperable broadband wireless connectivity to fixed and mobile users.
2. It provides up to 50km of service area.
3. Provides the users of broadband connection with no need of direct LOS.
4. Provides the users with total data rate up to 75Mbps which is enough for many different applications.(3)

2.4.4.WiMAX Construction

The WiMAX network consists of :

1. WiMAX base station: this includes a WiMAX tower and the indoor electronics. The connection of the tower and internet via high bandwidth wired connection. The base station antenna can be directional or omni directional; to provide both circular cell shapes and linear (sectoral) shapes for point to point communications.
2. WiMAX receiver: may take two forms, it could be stand alone, or Personal Computer Memory Card International Association (PCMCIA) that sits on the computer or laptop, or the receiver may have spate antenna to separate module.

3. There might also be other entities within the network, such as Repeater Stations (RSs) and routers, which provide connectivity of the network to one or more core or backbone networks.(3)

According to 802.16 standard, each coverage area consists of one BS and one or many Subscriber Stations (SSs). The BS provides the connection to the Core Networks (CNs), and completely controls when and how the SS can access the wireless network. The SS provides the customer (end user) the connection to the broadband wireless network.(10)

Access to a WiMAX base station is similar to accessing a wireless access point in a Wireless Fidelity (WiFi) network, but the coverage is greater. Figure 2.8.shows an example of 802.16 network coverage area. And Figure 2.9.shows an example of 208.16 network.(9)

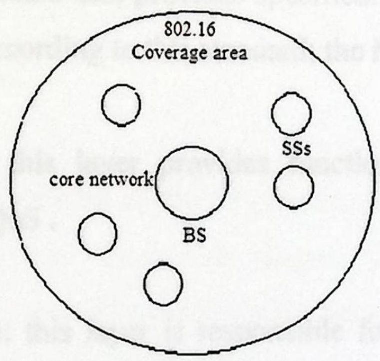


Figure 2.7. The 802.16 coverage area.(9),page20

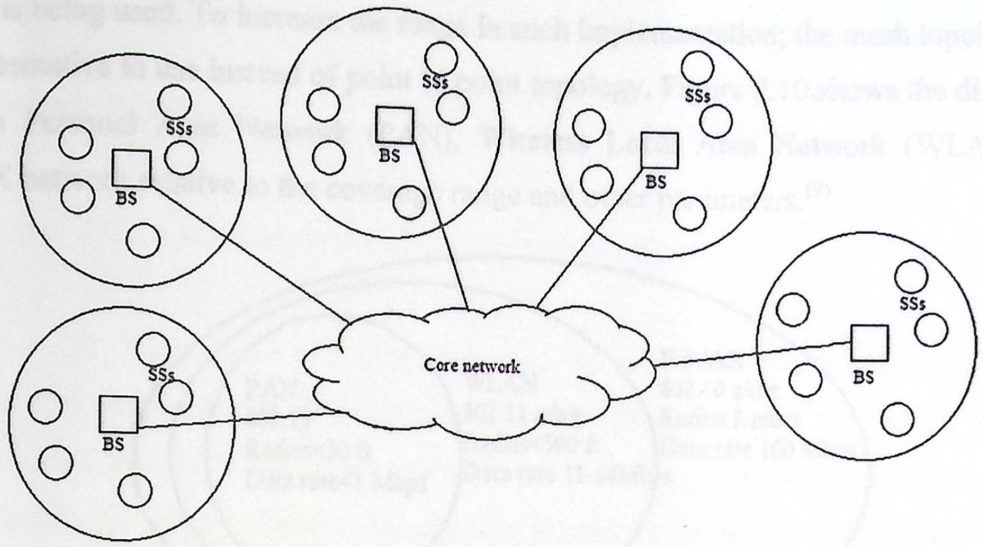


Figure 2.8. An example 802.16 network.[(9),page21]

2.4.5.WiMAX General Architecture(Layers)

IEEE 802.16 standard is a standard that provides specifications for Media Access Control (MAC) and Physical layers. According to this standard; the MAC layer is divided into three sub layers :

1. Convergence Sublayer (CS): this layer provides functions about duplexing, framing, initialization, channel access, QoS .
2. Security sublayer.
3. Common Part Sublayer (CPS): this layer is responsible for defining the medium access method , also it is considered as the center of MAC.[(10)]

2.4.6.WiMAX Versions

WiMAX passed through many amendments shown in table 2.1.(Appendix).

2.4.7.WiMAX Operating Range

Typically, the cell size is about 5 miles radius or less , this radius can reach up to 20 or sometimes 30 miles when there are suitable environment condition and given that

OFDM is being used. To increase the range in such implementation; the mesh topology is a good alternative to use instead of point to point topology. Figure 2.10.shows the difference between Personal Area Network (PAN), Wireless Local Area Network (WLAN) and WiMAX network relative to the coverage range and other parameters.[9]

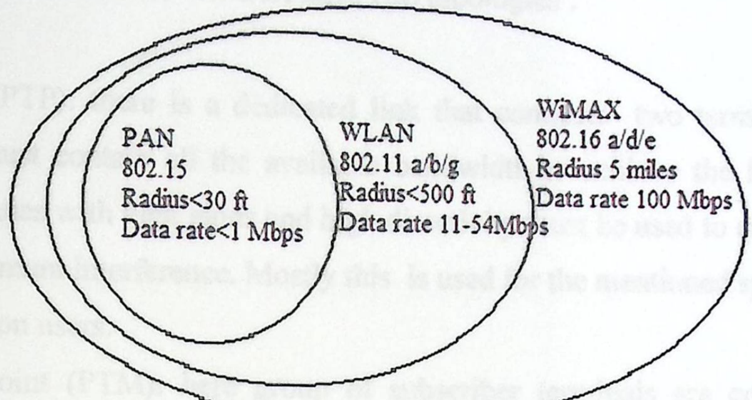


Figure 2.9. 802.16 system compared to other IEEE 802 standards.[(9),page74]

2.4.8.WiMAX Frequency Band

The frequency range is defined as the frequencies that lie between 2 and 66 GHz. This wide range is divided into three sub ranges; because the behavior of the electromagnetic wave is not the same all over this wide rang. The three bands are:

1. (10-66 GHz): this band is licensed band, the wavelength is very short, the attenuation is possible due to the physical geography of the environment or interference. The communication in this band needs a LOS between the BS and SS.
2. (2-11 GHz): this band is licensed band. The communication in this band doesn't require LOS between BS and SS, however the signal power may be significant.
3. (2-11 GHz): this band is unlicensed band. The physical characteristics of the 2-11 GHz unlicensed bands are similar to the licensed bands. However, because they are unlicensed, there are no guarantees that interference may not occur due to other systems using the same bands.[9]

Frequency bands of WiMAX different versions are shown in table 2.2.(Appendix).

2.4.9.Network Topology

According to 802.16 standard; WiMAX have two topologies :

1. Point To Point (PTP): there is a dedicated link that connects two terminals only. The dedicated link must contain all the available bandwidth to achieve the highest possible throughput, antennas with high gains and high directivity must be used to ensure maximum security and minimum interference. Mostly this is used for the mentioned special cases and not for the common users.
2. Point To Multipoint (PTM): here group of subscriber terminals are connected to BS separately. This is suitable for applications where there is no need for high bandwidth, here the bandwidth is shared between all users. A frequency reuse is needed, this can be carried out using sectored antennas with highly directional parabolic dishes (each dish refers to a sector).[9]

Either in PTP or PTM, the location of the BS much be chosen in a way to provide the best coverage. Figure 2.11.shows the point to point topology. And Figure 2.12.shows the point to multipoint topology.[9]

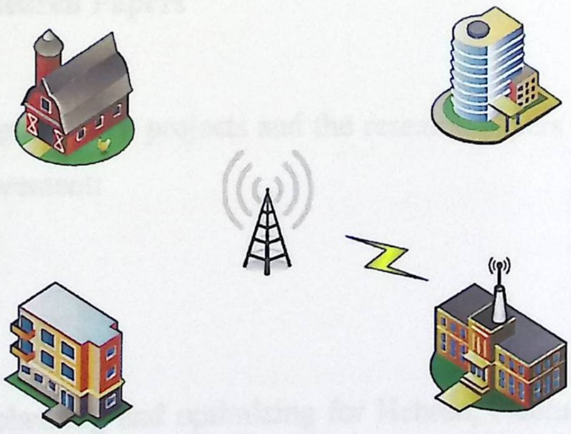


Figure 2.10. Point to point fixed wireless access.[(9),page122]

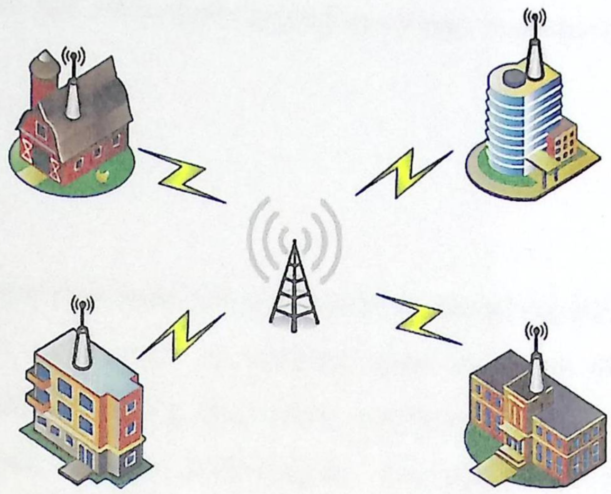


Figure 2.11. Point to multi point fixed wireless access.(9),page122

2.5.Brief General Comparison Between LTE And WiMAX

A brief general comparison between LTE and WiMAX shown in table 2.3. (Appendix) includes some important parameters such as frequency band, radio technology, channel bandwidth, capacity and other parameters.

2.6.Related Research Papers

2.6.1.LTE Related Research Papers

These are some of the graduation projects and the research papers that talk about the LTE performance and improvement:

<u>Graduation project:</u>

"LTE network planning and optimizing for Hebron, Nablus and Ramallah". Done by: Aleen Abu Rayyan, Lujain Mahde, Rawan Arafeh and Yasmeen Abu Omaer. In this project, number of base stations was distributed on the area of three main cities in Palestine depending on new technology of the 4G called LTE. Many adjustments were done on the base stations such that the cities gain a good coverage, capacity and quality of service values.

Research papers:

In [11], the paper discussed the advantages of the advanced LTE which have been developed by 3GPP, as a way to enhance some issues in 4G technology, these enhancements include increasing data rates, improve coverage, reduced latency and interworking with other telecom technologies. The paper also takes about the LTE architecture and mobility features.

In [12], this paper proposed an LTE femto cell coverage adjustment mechanism. The mechanism can determine and adaptively adjust the appropriate femto cell coverage when interference occurred depending on collected information from User Equipment (UE) and femto cell. By this mechanism, the interference could be mitigated and reduced for 29.5 %.

In [13], the paper perform an analysis of the OFDMA and SC-OFDMA as a multiple access technique used in LTE, the study based on peak average power ratio and considered an Additive White Gaussian Noise (AWGN) channel in the error performance analysis.

In [14], this paper discussed the need of data transfer across mobiles as a reason of moving from 4G to LTE, the paper performed an analysis of TDD LTE and compare its performance with FDD LTE.

In [15], this paper discussed the evolution of technology and the need of high data rate that led to the appearance of 3rd, 4th and LTE technologies by 3GPP. The paper discussed the requirement of each technology, and study the performance (in terms of BER and symbol rate) of OFDM LTE under scenarios of channels that have multipath propagation and AWGN.

2.6.2. WiMAX Related Research Papers

These are some of the research papers talk about the WiMAX performance and improvement:

In [16], a study has been done on the performance of WiMAX Networks based on MIMO and Adaptive Modulation and Coding (AMC). AIRCOM International's radio network planning tool has been used for analysis. The results of this analysis is in terms of coverage and capacity, pointing to the trade offs with MIMO and AMC in Mobile WiMAX Networks.

In [17], there is a trend toward improving the cellular WiMAX network for emergency and safety services by using overlaid WiMAX cellular structure. A micro cell has been used for covering urban hotspots over a macro cell structure. This plan take into consideration the Signal to Interference and Noise Ratio (SINR) value. The plan based on using the sectorization to reduce the patterns reuse and to increase the capacity, while using the overlay network to overcome the coverage problems in large towns and cities. It concludes that possible lower values of antenna's gain could be used depending on 3.5 GHz bands instead of 5.8 GHz bands.

In [18], a study has been done to evaluate the WiMAX range and coverage probability by using the Stanford University Interim (SUI) channel model. This study also use Smart Antenna System (SAS) to improve the network performance. The evaluation results show that with SAS, the cell radius is at least 30% more than that without SAS.

In [19], a software platform for the MAC layer has been designed, and some optional mechanisms applied on it. And many complex algorithms were tested based on this software platform to serve better QoS in WiMAX networks.

In [20], a new scheduling scheme is proposed to improve delay time parameter. This parameter improvement is added to the fair scheduling schemes so that the total QoS is improved.

In [21], an admission control scheme for services is proposed. This scheme is defined in the 802.16 specifications. It provides the highest priority to the Unsolicited Grant Service (UGS) flows. Also the bandwidth utilization is maximized by bandwidth borrowing and return. And an analytical model developed to evaluate the network performance.

In [22], a novel scheduling algorithm used to provide different QoS for each service types. This algorithm based on allocating the resources for each service types in terms of slots. The number of slots determined based on the minimum and maximum bandwidth required for each service type. Also the algorithm depends on the priority scheduling such that the service with highest QoS requirement is served first.

In [23], a WiMAX QoS management model is proposed for a central structure in which the central base station schedules the best effort and VOIP traffics over several subscriber stations.

In [24], an improvement of the coverage and capacity parameters has been done depending on WiMAX macro base stations and femto Access Points (APs). Femto AP is useful for indoor coverage and capacity improvement where the macro base station may be weak. Also a spatial reuse of wireless spectrum is used to improve the capacity.

In [25], an evaluation for the downlink performance of a mobile WiMAX with different radio resource management like scheduler for QoS control and the implementation for multi connection.

In [26], a study and a discussion of the important scheduling parameters has been made to be considered in the future scheduling mechanisms. And a survey done for the recent scheduling researches that propose different scheduling mechanisms to improve QoS in WiMAX.

Chapter 3

Planning

Contents

3.1.Mentum Planet Tool Overview

Mentum Planet tool helps wireless network designers to design a good wireless network using different technologies. WiMAX, LTE and 3G are examples of that technologies of wireless networks.

Mentum Planet provides many features that help for accurate design, analysis and optimization for wireless networks.

In this program, the designer could choose any area, city or country to make a wireless network design for it.

In any wireless design, there are many important settings to be considered and adjusted. These parameters could be divided into two types:

1. Network settings.
2. Subscribers settings.

Network settings include network technology type which could be WiMAX, LTE, 3G or other technologies. Also include spectrum allocation, here we determine the frequency band of the network.

Subscriber settings include antenna type, service type (data, voice, web, etc …) and many other parameters.

Network frequency band is an important issue. Frequency band affects the data rate, the coverage (so the number of needed sites) and the interference value.

The propagation model is also an important point to be considered. There are a lot of propagation models that can be used to predict the behavior of the radio signal in a certain area. Each model has its own equation which contains several parameters. According to the type of those parameters, the model could be suitable for some areas and not for the others.

3.2. Propagation Model

Here in our study, we use the Planet General Model (PGM) which is a good propagation model to use for frequencies between 150 and 2000 MHz where the distance between the transmitter and the receiver ranges between 1 and 100 kilometers. Ideally, when using this model, the base station antenna heights should range between 30 and 1000 meters and the mobile station antenna heights should be between 1 and 10 meters.[27]

The received signal strength at the mobile is given by the following equation:

$P_{PX} = P_{TX} + K_1 + K_2 \log(d) + K_3 \log(H_{eff}) + K_4 \text{ Diffraction} + K_5 \log(H_{eff}) \log(d) + K_6 (H_{meff}) + K\text{clutter} \ldots$ [27]

- P_{PX} is the receive power. (dBm)
- P_{TX} is the transmit power (ERP). (dBm)
- K_1 is the constant offset. (dB)
- K_2 is the multiplying factor for log(d).

both K_1 and K_2 can be assigned two sets of values. One set is used for d< distance and the other for d> distance, where distance is the distance in meters away from the base site specified in the Model Editor.[27]

- K_3 is the multiplying factor for $\log(H_{eff})$. It compensates for gain due to antenna height.
- K_4 is the multiplying factor for diffraction calculation.
- K_5 is the Okumura-Hata type of multiplying factor for $\log(H_{eff}) \log(d)$.
- K_6 is correction factor for the mobile effective antenna height gain ($K_6 H_{meff}$).
- d is the distance, in meters, of the receiver from the base site.
- H_{eff} is the effective height of base site antenna from ground.

The effective antenna height (H_{eff}) in meters described in the previous equation may be calculated from any one of the following variables:

- Base height
- Spot height
- Average height
- Slope
- Ground Reflection Slope
- Profile
- Absolute spot height[27]

Here is a brief description of two simple variables that could be used to calculate the effective antenna height:

1. Base height

Effective antenna height (H_{eff}) is set equal to the base site height above ground.[27]

2. Spot height

If $H_{0b} > H_{0m}$ then $H_{eff} = H_b + H_{0b} - H_{0m}$

If $H_{0b} \leq H_{0m}$ then $H_{eff} = H_b$

Where:

H_b is the antenna height above ground at the base site.

H_{0b} is the terrain height above sea level at the base site.

H_{0m} is the terrain height above sea level at the mobile site.[27]

- Diffraction is the value calculated for loss due to diffraction over an obstructed path. The value produced is a negative number so a positive multiplication factor, K_4 is required.
- K clutter is the gain in dB for the clutter type at the mobile position in Planet DMS. In Mentum Planet, K clutter represents a loss.
- H_{meff} is the mobile effective antenna height.[27]

The standard propagation model uses the mobile effective antenna height together with a linear correction factor (K_6):

$H_{meff} = (h_{0m} + h_m) - h_{0b}$ … [27]

To show how PGM is different from other models, we referred it to well-known models such as HATA and OKUMURA models, and try to find how much they are related to or different from PGM.

The Okumura-Hata model is an empirical formulation of the graphical path loss data provided by Yoshihisa Okumura, and is valid from 150 MHz to 1500 MHz. The Hata model is, basically, a set of equations based on measurements and extrapolations from the curves derived by Okumura. Hata presented the urban area propagation loss as a standard formula, along with additional correction factors for application in other situations such as suburban and rural.[28]

Hata model neglects the terrain profile between the transmitter and receiver, that is, hills or other obstacles between the transmitter and receiver are not considered. So we choose PGM model in the planning because it does not neglects the terrain profile between the transmitter and the receiver. Both Hata and Okumura made the assumption that the transmitters would normally be located on hills. Figure 3.1. shows a typical scenario for Hata-Okumura model.[28]

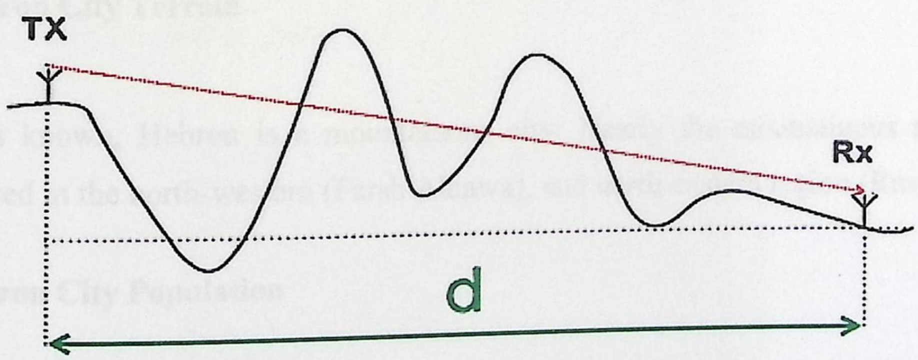


Figure 3.1. Hata-Okumura typical scenario.[28]

The above model assumes a direct line-of-sight path from transmitter (tx) to receiver (rx) but the actual path is obstructed by two hills. Hence, the prediction would be too optimistic.

The standard Hata formula for median path loss in urban areas is given by:

$$L(urban)(dB)= 69.55 + 26.16\log f_c - 13.82\log h_{tx} - a(h_{rx}) + (44.9 - 6.55\log h_{tx}) \log d$$

f_c is the frequency (in MHz) from 150 MHz to 1500 MHz.

h_{tx} is the effective transmitter antenna height (in m) ranging from 30m to 200m.

h_{rx} is the effective receiver antenna height (in m) ranging from 1 m to 10 m.

d is the T-R separation distance (in km).

$a(h_{rx})$ is the correction factor for effective antenna height which is a function of the size of the coverage area.[28]

To obtain the path loss in a suburban area, the standard Hata model formula is modified to:

$$L(dB)= L(urban) - 2[\log(f_c/28)]^2 - 5.4$$

The antenna correction factor is given by:

$$a(h_{rx})= (1.1 \log f_c - 0.7)h_{rx} - (1.56 \log f_c - 0.8) \text{ dB} \ldots$$ [28]

3.3.Hebron City

3.3.1.Hebron City Terrain

As known, Hebron is a mountainous city. Nearly the mountainous regions are concentrated in the north-western (Farsh Alhawa), and north-eastern region (Ras Aljorah).

3.3.2.Hebron City Population

The population is nearly concentrated in the western region (Alsalam street), south-eastern region (The Industrial Region), and central region (Bab Alzawyah).

These two parameters should be taken into consideration of planning. Wherever the areas are highly populated, there is a need to more base stations there than the other areas. Also it is good to allocate the base station at an appropriate height that is not very high to avoid the LOS between base stations to avoid the interference, and not very low height such that it can not cover the required area.

3.4.Planning Details

Planning Steps And Results:

1. Here is Hebron City as a part of Palestine. Its area size is nearly 36.8 Km^2

Figure 3.2.Hebron City.

2. Hebron City on the Mentum planet tool.

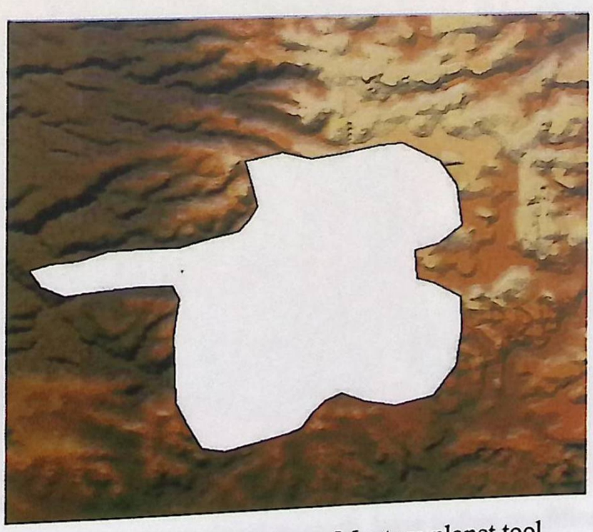


Figure 3.3.Hebron City on Mentum planet tool.

3.4.1. WiMAX Planning Details

There are some important parameters to be adjusted first for TDD WiMAX:

1. The network technology is selected to be WiMAX.
2. This network frequency band is 2300, 2500, and 3500 MHz..
3. One antenna is used for both Tx and Rx (i.e. MIMO is 1x1).
4. TDD used as multiplexing technique.
5. The best antenna type to use is DBXLH-6565C-VTM which is directional antenna.
6. The propagation model is set to be Planet General Model (PGM).
7. The total power (EIRP) is 62.35 dBm.
8. All modulation types here are enabled, the network choose the appropriate type for each user.

Best server signal strength layer:

- Frequency band 2300 MHz.

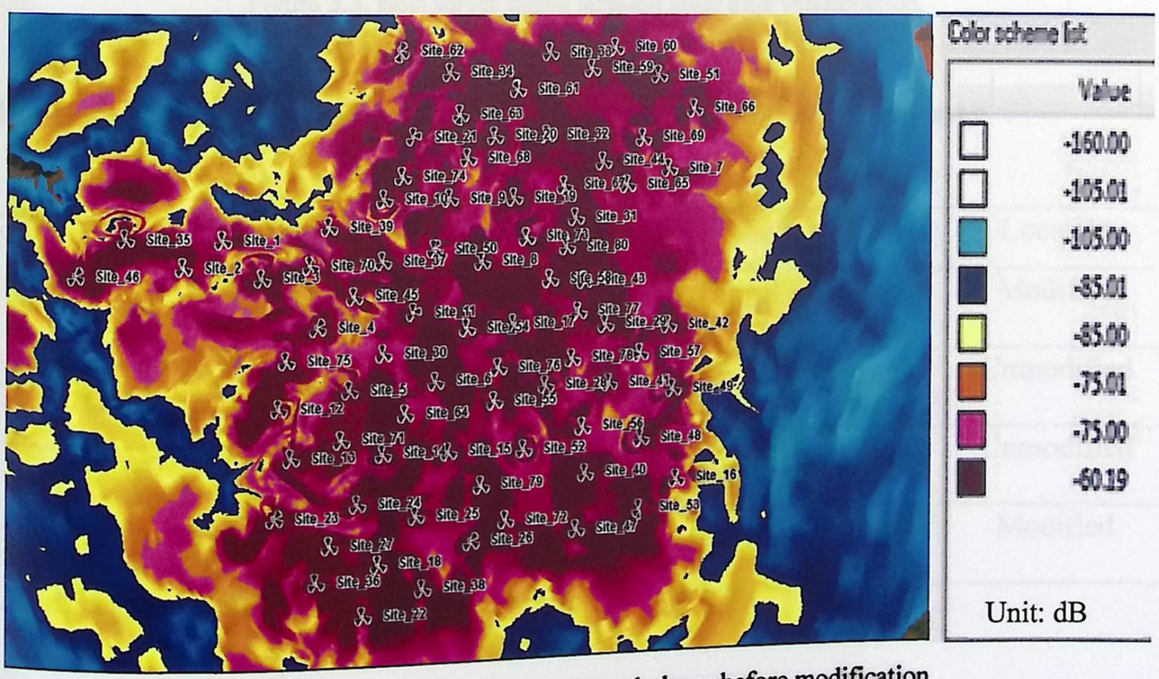


Figure 3.4. Best server signal strength layer before modification

As noticed in the figure, about 80 sites were enough to provide a -60 dB which is considered to be a good signal strength. Nearly as shown, all the area is covered by that good signal strength. No modifications are needed for this layer, but some modifications must be done to improve the other layers which will make no effects on this layer since it is good.

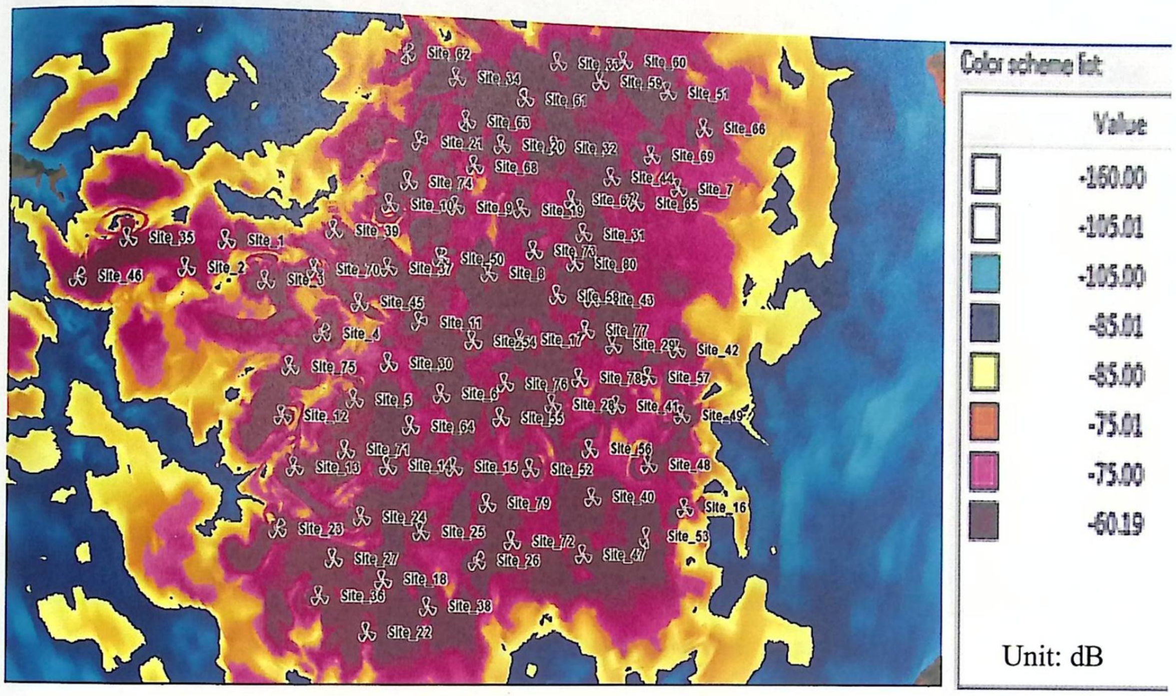


Figure 3.5. Best server signal strength layer after modification.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
23	0°	+7°(up)	0°,120°,240°	45°,120°,240°	Modified
26	0°	+7°(up)	0°,120°,240°	45°,120°,240°	Unmodified
31	+7	0 (down)	0°,120°,240°	0°,120°,240°	Unmodified
53	0°	-7°(down)	0°,120°,240°	0°,220°,240°	Modified

As said before, the performed modifications did not affect the signal strength layer, its effect will appear on the other layers.

- Frequency band 2500 MHz.

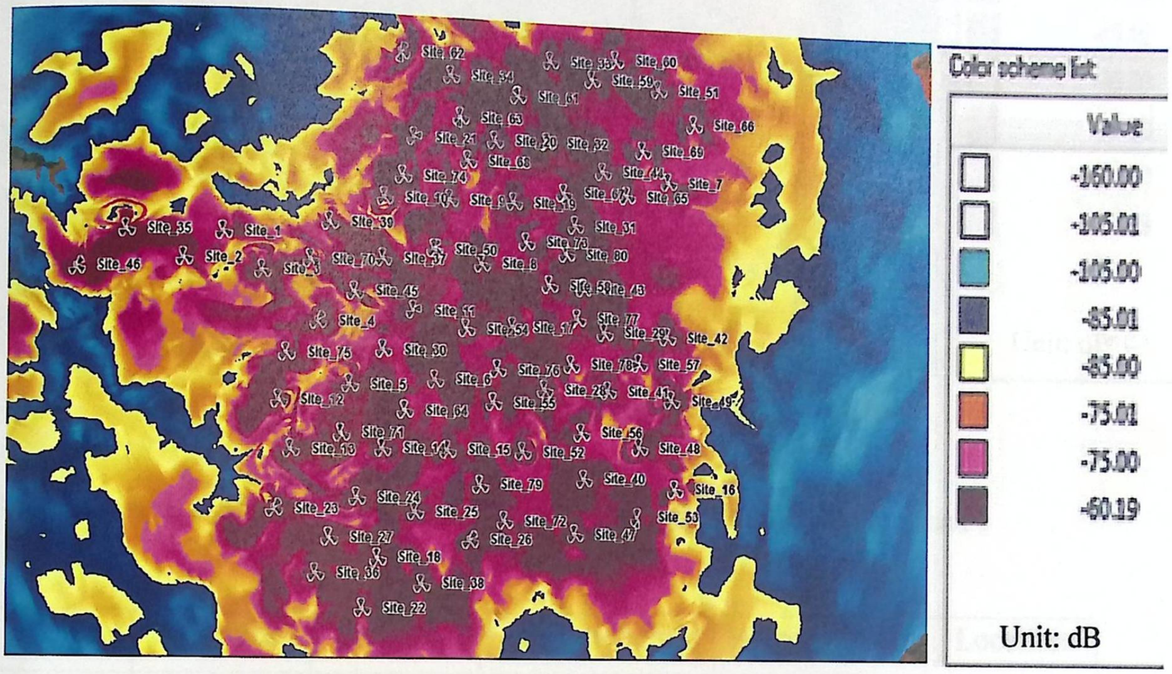


Figure 3.6. Best server signal strength layer before modifications.

After changing the frequency band from 2300 MHz to 2500 MHz, signal strength value in some regions slightly decreased. So additional sites will be needed to overcome this decreasing.

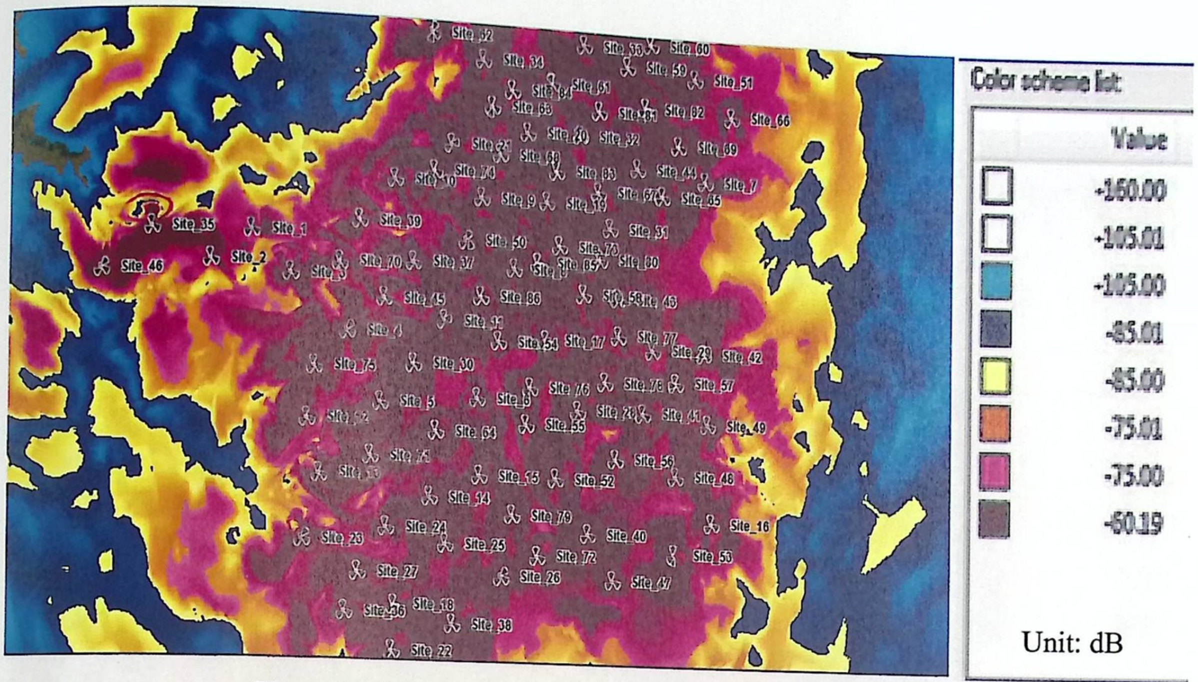


Figure 3.7. Best server signal strength layer after modifications.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
50	-7°	$+7^\circ$ (up)	$0^\circ,120^\circ,240^\circ$	$30^\circ,150^\circ,240^\circ$	Modified
62	0°	$+7^\circ$ (up)	$0^\circ,120^\circ,240^\circ$	$30^\circ,120^\circ,220^\circ$	Modified
82	-10°	0° (up)	$0^\circ,120^\circ,240^\circ$	$0^\circ,135^\circ,240^\circ$	Modified
86	$+10^\circ$	7° (down)	$0^\circ,120^\circ,240^\circ$	$0^\circ,120^\circ,240^\circ$	Modified

After many trials of improving the signal strength value, the placement of additional sites was the best way to achieve this improvement. This is a logical decision since the frequency band now is 2500 MHz is higher than 2300 MHz, so 6 sites were added to get about 86 sites finally which were enough to get the satisfactory coverage.

- Frequency band 3500 MHz.

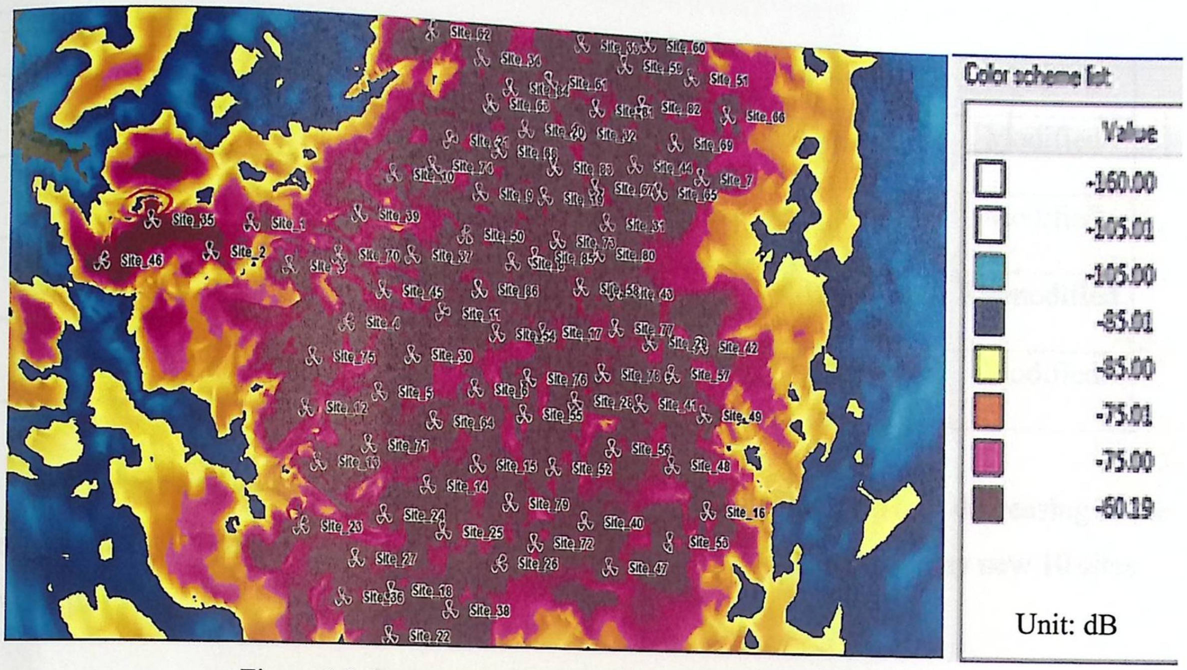


Figure 3.8. Best server signal strength layer before modifications.

After moving from 2500 MHz to 3500 MHz, the 86 sites (which were acceptable in 2500MHz) become not enough to cover all the area with a good signal strength. A bad coverage areas can be noticed from figure 3.8.

Figure 3.9. Best server signal strength layer after modifications.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
11	-7°	+7° (up)	0°,120°,240°	45°,80°,240°	Modified
85	0°	+7° (up)	0°,120°,240°	45°,160°,240°	Modified
90	+7	10 (up)	0°,120°,240°	0°,120°,240°	Unmodified
95	0°	-10° (down)	0°,120°,240°	0°,120°,240°	Modified

Since that frequency band 3500 MHz is higher than 2500 MHz, a decreasing in the signal strength value will be faced in some areas. This is the reason of why new 10 sites were placed.

Downlink C over I layer:

- Frequency band 2300 MHz.

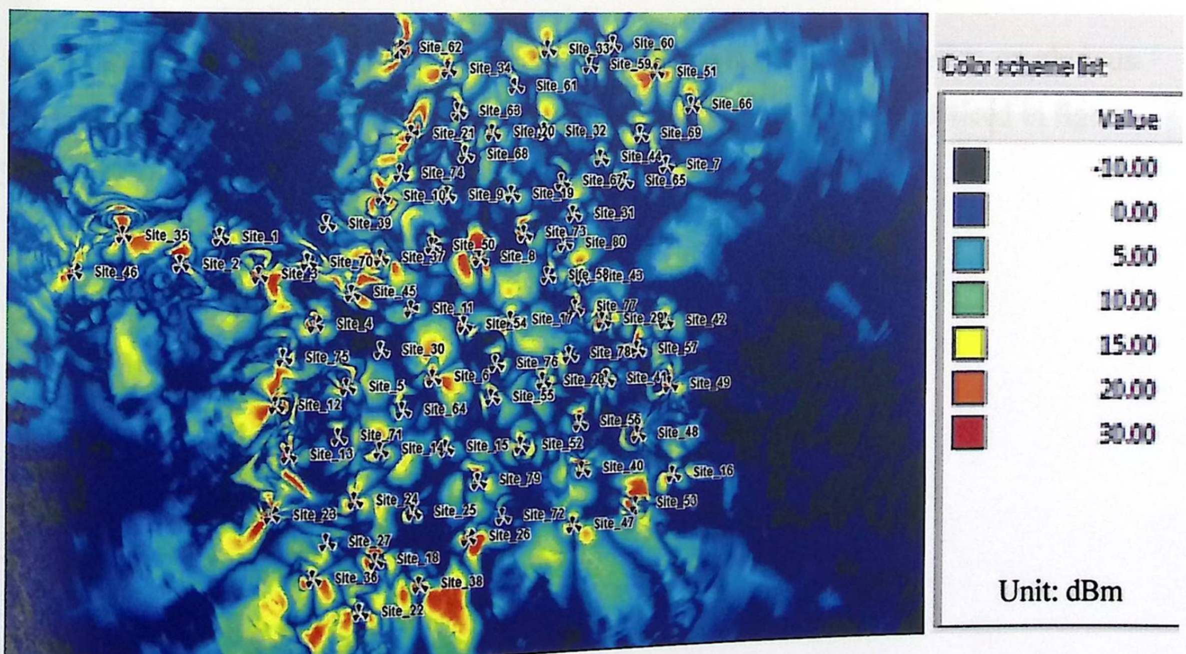


Figure 3.10. Downlink C over I layer before modifications.

As noticed in the figure, wide areas suffer from a high interference percentage (i.e. low Carrier To Interference (C/I) value), so some modifications are needed to increase the carrier to interference value in that areas. These modifications may include changing the tilt, azimuth, height of the antenna and sometimes the site location.

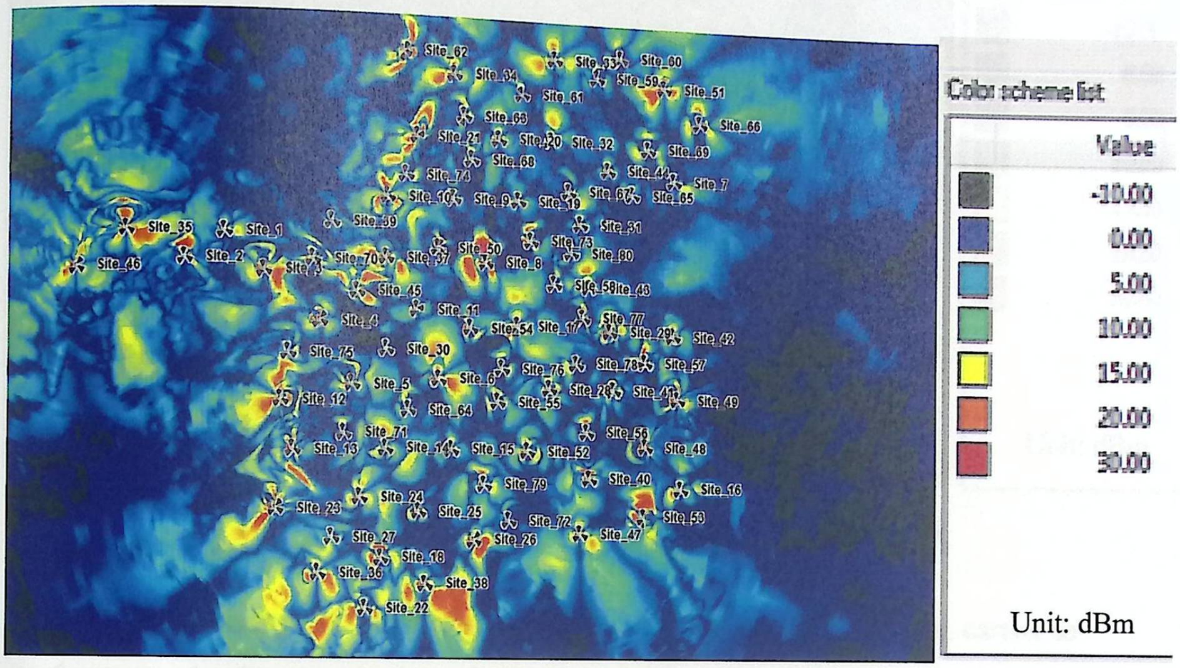


Figure 3.11. Downlink C over I layer after modifications.

After carrying out the mentioned adjustment of the sites' parameters, an obvious improvement on the carrier to interference value in many areas can be noticed in figure 3.11.

- Frequency band 2500 MHz.

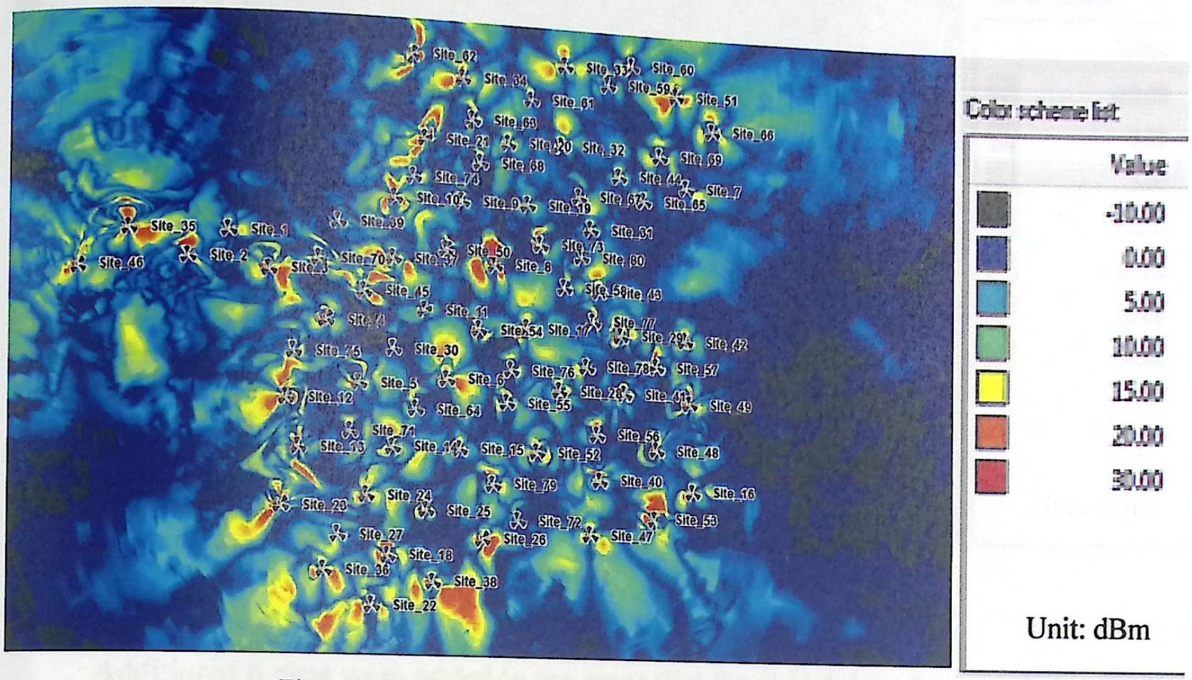


Figure 3.12. Downlink C over I layer before modifications.

After changing the frequency band from 2300 MHz to 2500 MHz, carrier to interference value in some regions dropped, and this will increase the interference and affect the quality of service badly. So many modifications and additional sites will be needed to overcome this problem and keep an acceptable quality of service.

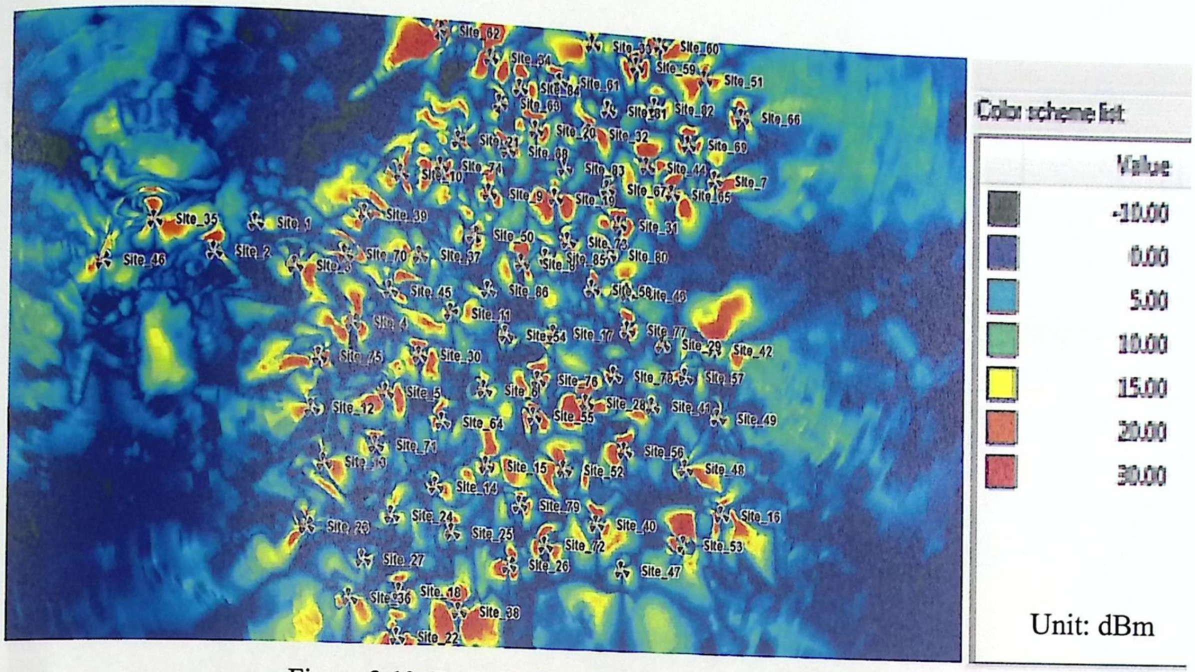


Figure 3.13. Downlink C over I layer after modifications.

Additional 6 sites were added to the areas that faced high interference. An increasing in the carrier to interference percentage can be noticed in such regions.

- Frequency band 3500 MHz.

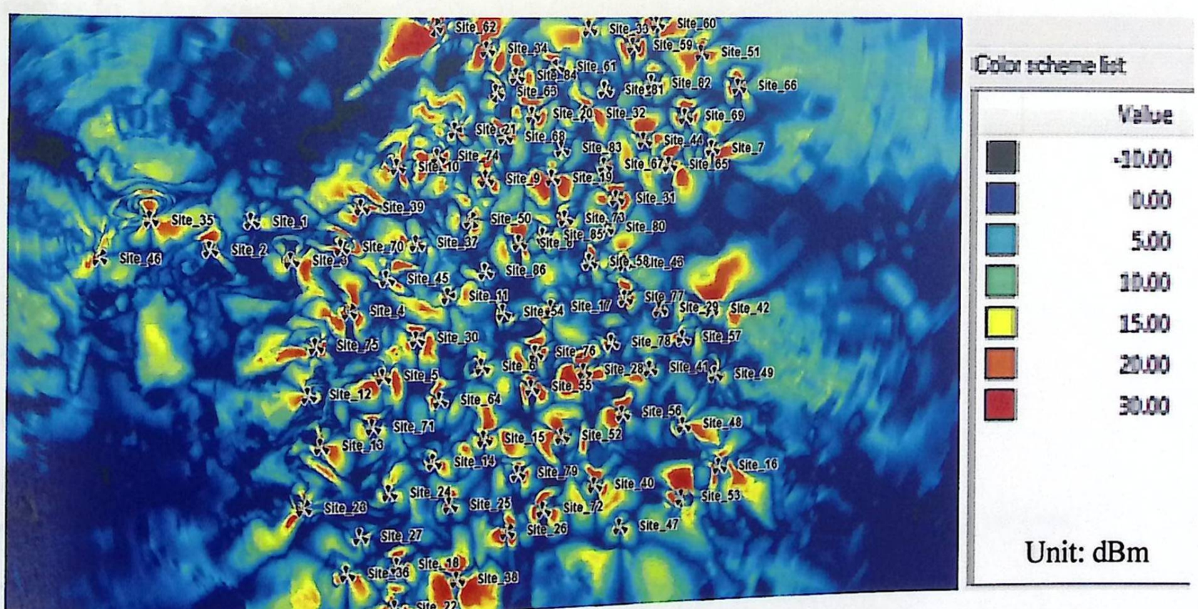


Figure 3.14. Downlink C over I layer before modifications.

After moving from 2500 MHz to 3500 MHz, the 86 sites (which provide acceptable QoS in 2500MHz) become not enough to provide a good quality of service (i.e. high C/I value). Many areas suffer from high interference as noticed in figure 3.14.

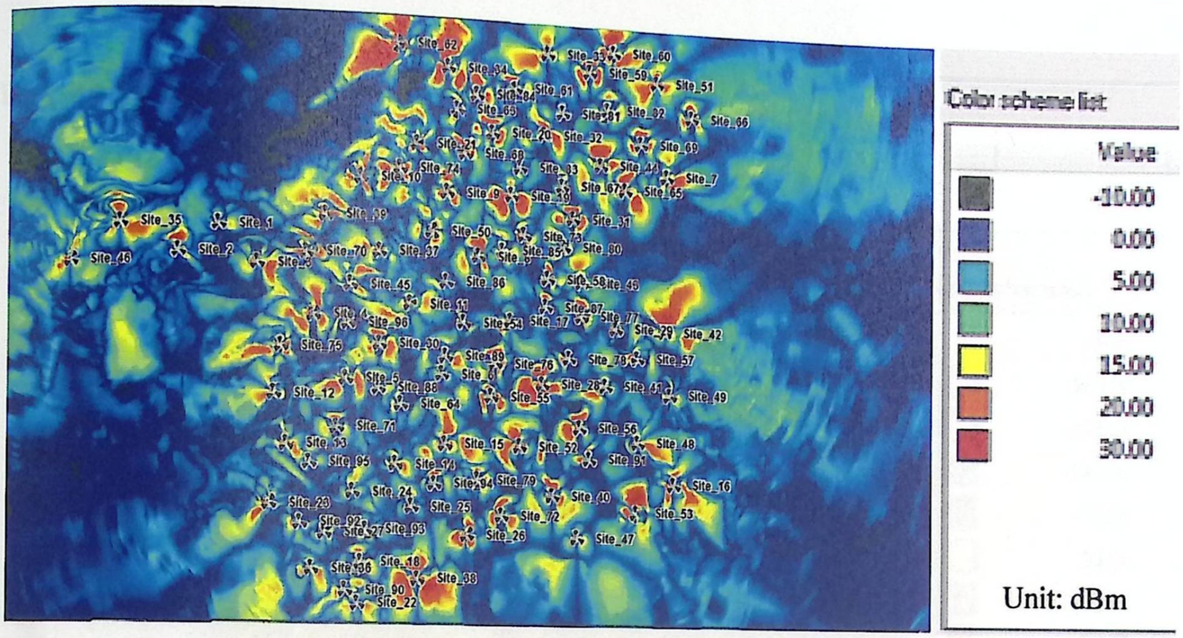


Figure 3.15. Downlink C over I layer after modifications.

Since that frequency band 3500 MHz is higher than 2500 MHz, a decreasing in the carrier to interference value will be faced in some areas. This is the reason of why new 10 sites were placed and many modifications were done.

There are some important parameters to be adjusted first for FDD WiMAX:

1. The network technology is selected to be WiMAX.
2. This network frequency band is 2300, 2500, and 3500 MHz..
3. One antenna is used for both Tx and Rx (i.e. MIMO is 1x1).
4. FDD used as multiplexing technique.
5. The best antenna type to use is DBXLH-6565C-VTM which is directional antenna.
6. The propagation model is set to be Planet General Model (PGM).
7. The total power (EIRP) is 62.35 dBm.

8. All modulation types here are enabled, the network choose the appropriate type for each user.

Best server signal strength layer:

- Frequency band 2300 MHz.

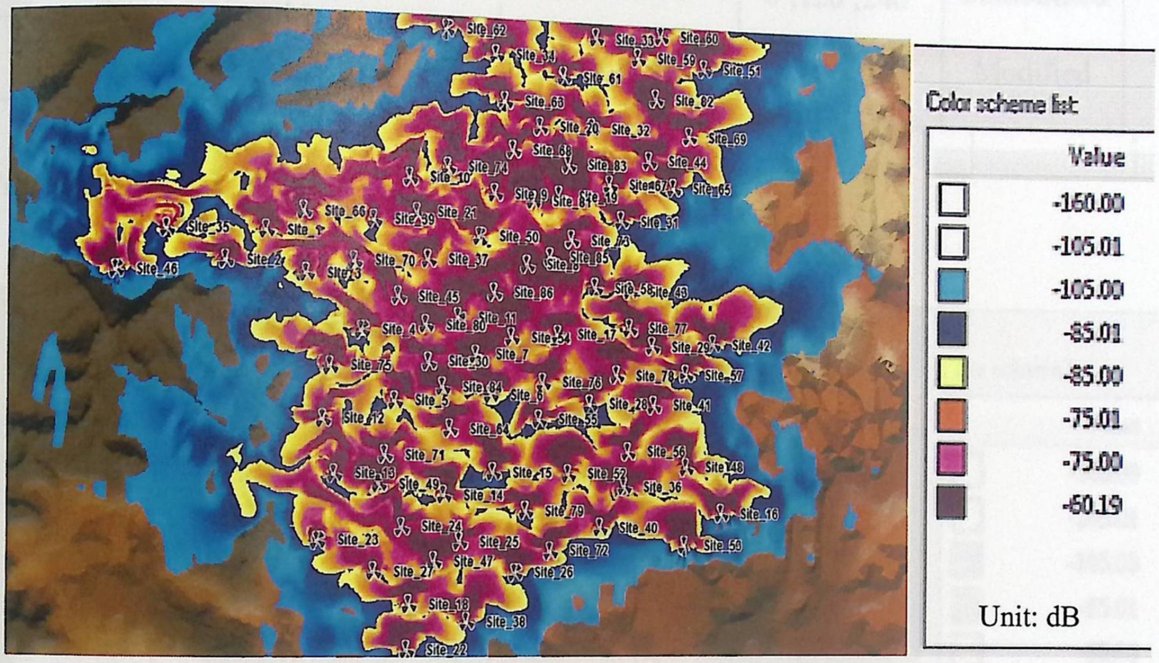


Figure 3.16. Best server signal strength layer after modifications.

Most of the area is covered by -85 dB and -75 dB signal strength value which considered to be good. This coverage was achieved after many modifications and placement of 86 sites on the area.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
60	-7°	$+7^{\circ}$ (up)	$0^{\circ},120^{\circ},240^{\circ}$	$0^{\circ},120^{\circ},240^{\circ}$	Unmodified
67	$+10^{\circ}$	$+7^{\circ}$ (down)	$0^{\circ},120^{\circ},240^{\circ}$	$0^{\circ},120^{\circ},240^{\circ}$	Unmodified
73	+7	0 (down)	$0^{\circ},120^{\circ},240^{\circ}$	$0^{\circ},120^{\circ},240^{\circ}$	Unmodified
76	0°	-10° (down)	$0^{\circ},120^{\circ},240^{\circ}$	$0^{\circ},120^{\circ},240^{\circ}$	Modified

- Frequency band 2500 MHz.

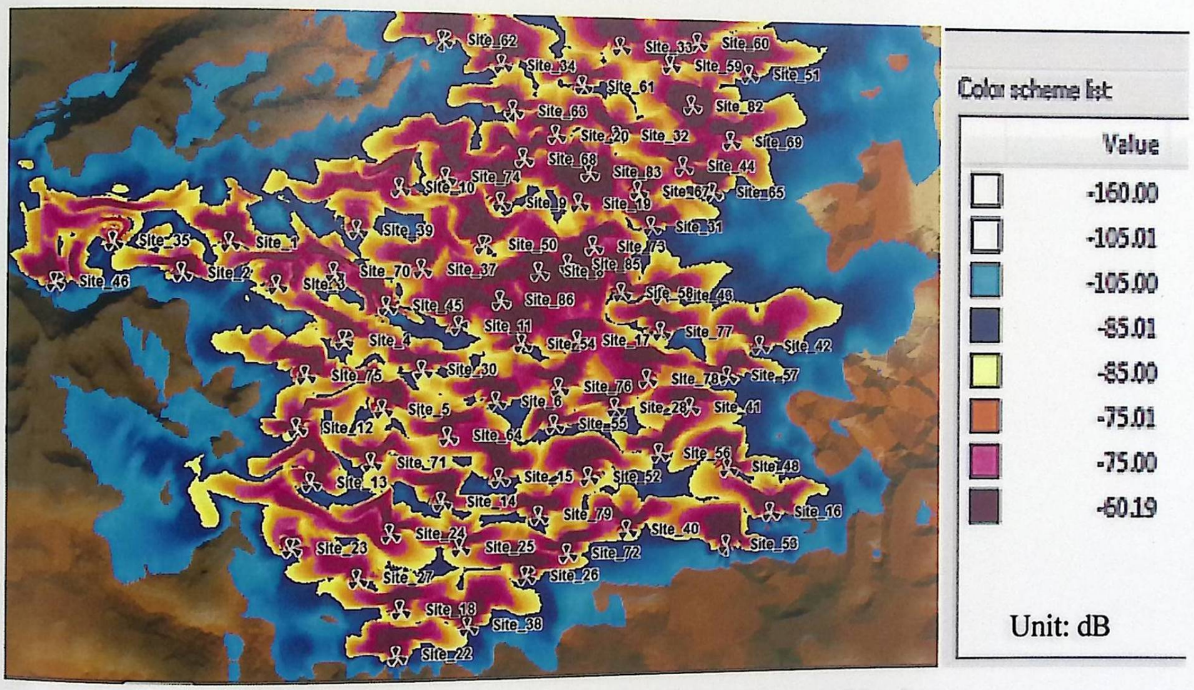


Figure 3.17. Best server signal strength layer after modifications.

For frequency band 2500 MHz, no additional sites were added because there is no need for that; the decreasing and the difference in the coverage between 2300 MHz and 2500 MHz is very small and acceptable. So only some modifications on the sites were done.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
30	0°	+7° (up)	0°,120°,240°	0°,120°,240°	Modified
45	+7°	0° (down)	0°,120°,240°	0°,120°,240°	Modified
54	+10	0 (down)	0°,120°,240°	0°,120°,240°	Modified
84	0°	-7° (down)	0°,120°,240°	0°,120°,240°	Modified

- Frequency band 3500 MHz.

Figure 3.18. Best server signal strength layer after modifications.

The decreasing and the difference in the coverage between this frequency and the previous frequencies is noticed, so additional 10 sites were added to overcome this decreasing. And some modifications on the sites were done.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
88	-10°	+7°(up)	0°,120°,240°	50°,120°,260°	Modified
89	+7°	+10°(up)	0°,120°,240°	0°,120°,240°	Unmodified
94	+7	0 (down)	0°,120°,240°	0°,120°,240°	Modified
96	-10°	-7°(up)	0°,120°,240°	0°,120°,240°	Modified

Downlink C over I layer:

- Frequency band 2300 MHz.

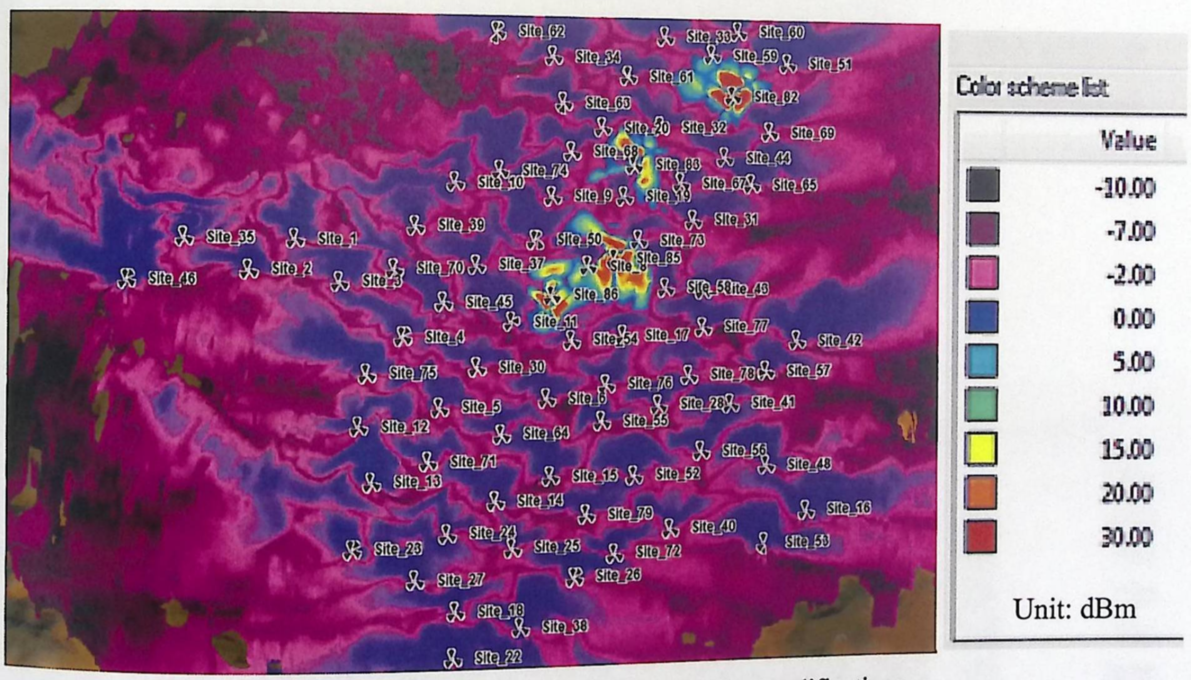


Figure 3.19. Downlink C over I layer after modifications.

86 sites were enough as shown in the figure, high carrier to interference value (30 dBm and 20 dBm) is provided from 4 sites only. The other sites provide average carrier to interference value about -2 to 0 dBm which is acceptable value for good QoS.

- Frequency band 2500 MHz.

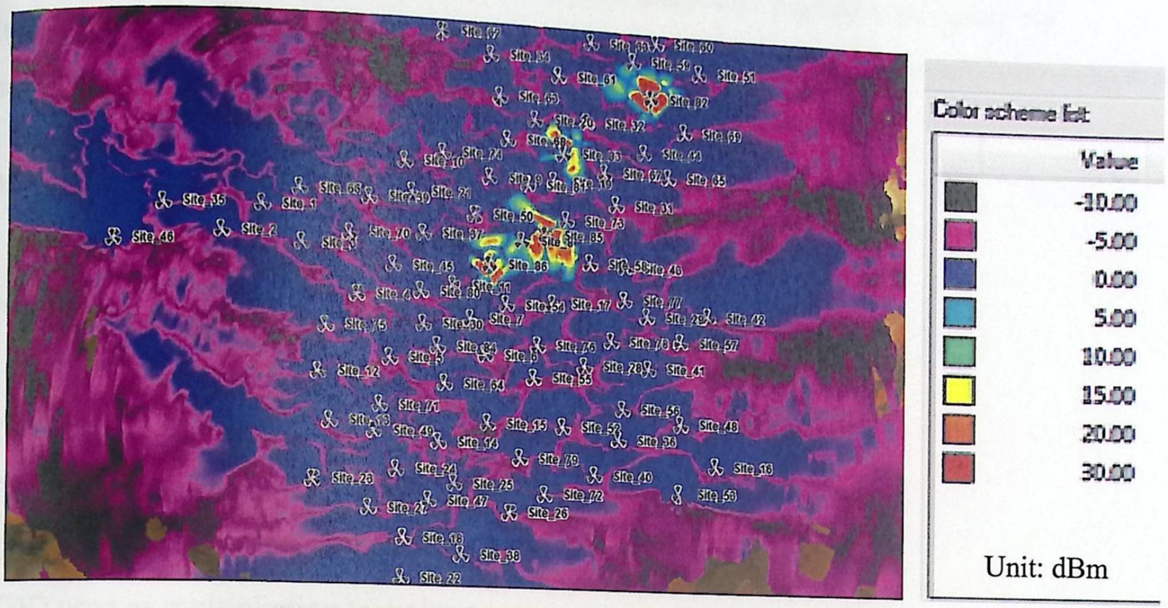


Figure 3.20. Downlink C over I layer after modifications.

The average carrier to interference value provided is about -2 to 0 dBm which is close to the previous frequency; so the number of sites is the same 86 and no additional sites needed.

- Frequency band 3500 MHz.

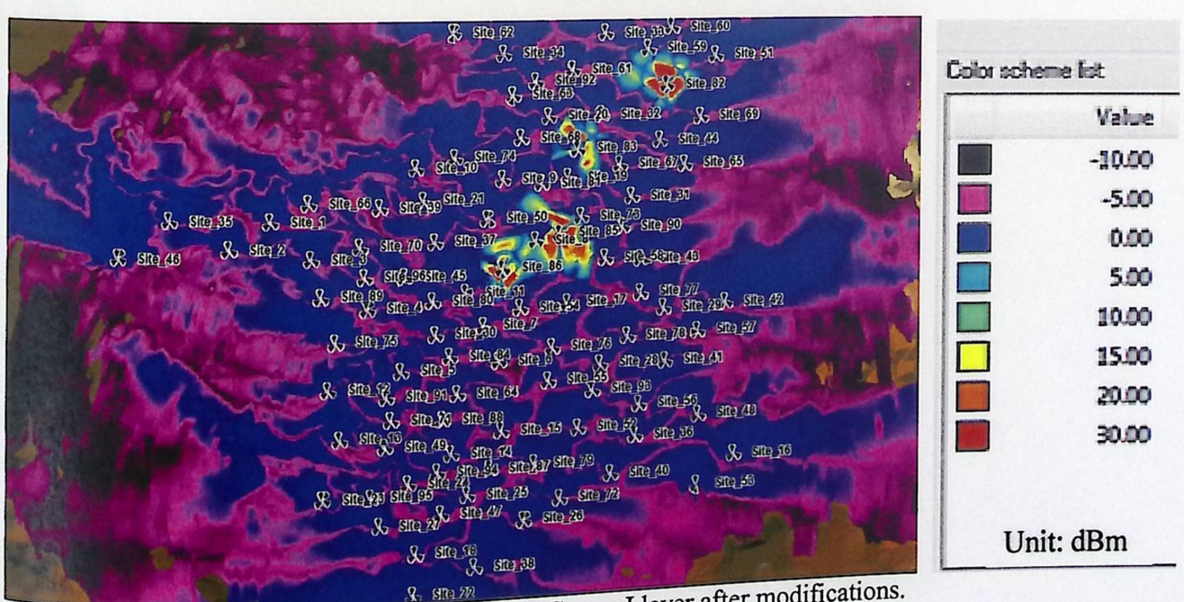


Figure 3.21. Downlink C over I layer after modifications.

Because of the high frequency band 3500 MHz, an obvious decreasing in the carrier to interference value happened; so additional 10 sites were needed to decrease the interference. 96 sites provide an average carrier to interference value about 0 dBm which is acceptable for good QoS.

3.4.2.LTE Planning Details

There are some important parameters to be adjusted first:

1. The network technology is selected to be LTE.
2. This network frequency band is 1800, 2100, and 2600 MHz..
3. One antenna is used for both Tx and Rx (i.e. MIMO is 1x1).
4. TDD used as multiplexing technique.
5. The best antenna type to use is DBXLH-6565C-VTM which is directional antenna.
6. The propagation model is set to be Planet General Model (PGM).
7. The total power (EIRP) is 62.35 dBm.
8. All modulation types here are enabled, the network choose the appropriate type for each user.

Best server signal strength layer:

- Frequency band 1800 MHz.

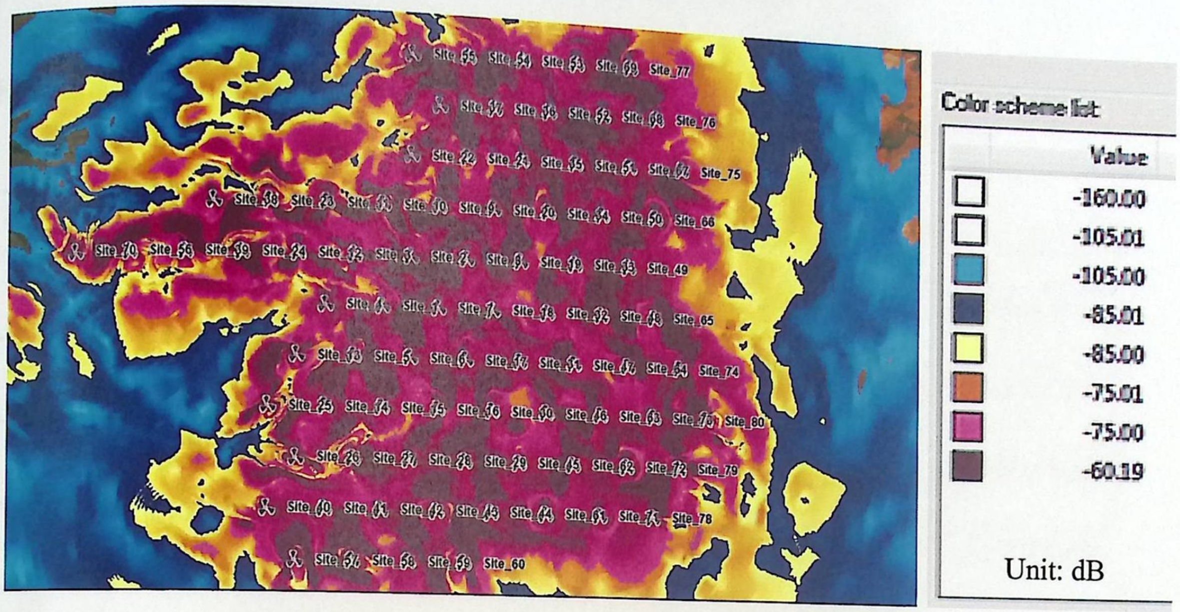


Figure 3.22. Best server signal strength layer before modifications.

At the beginning, 80 sites had been located automatically without any modifications. As shown in figure 3.22. the coverage is nearly very good -60 dB. Some small areas have a signal strength of -75 dB.

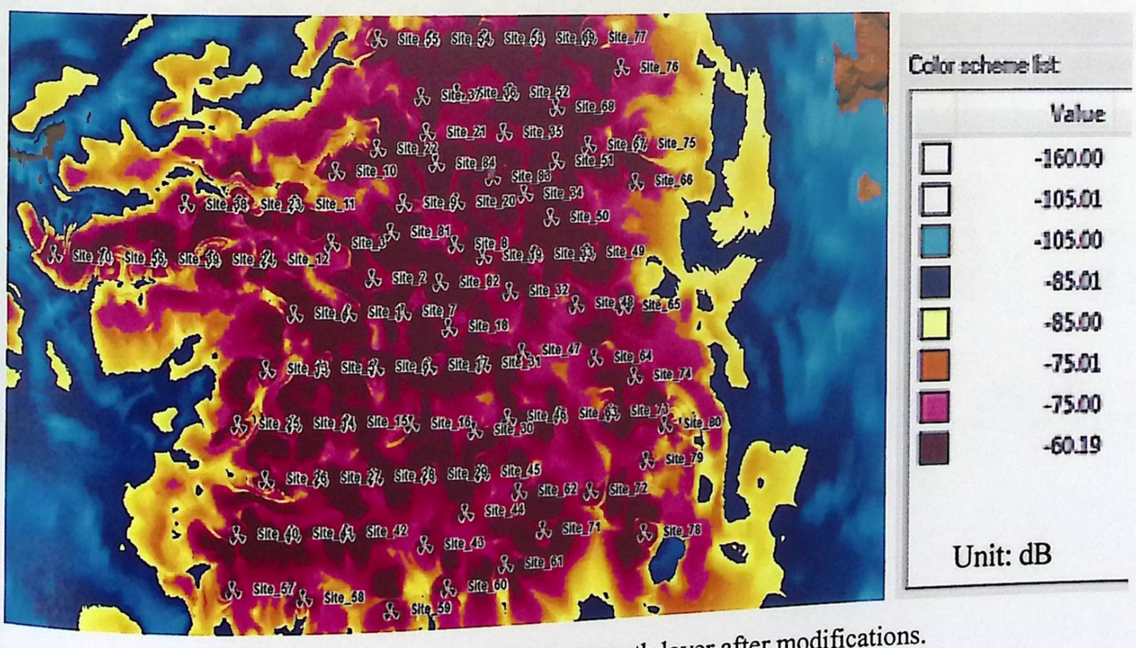


Figure 3.23. Best server signal strength layer after modifications.

Some modifications on the sites had been done to decrease the percentage of the area that covered with signal strength of -75 dB. Modifications on the site location, azimuth, and tilt were done. And another 4 sites were added.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
5	-7°	$+7^\circ$ (up)	$0^\circ,120^\circ,240^\circ$	$25^\circ,120^\circ,240^\circ$	Modified
20	0°	$+7^\circ$ (up)	$0^\circ,120^\circ,240^\circ$	$45^\circ,120^\circ,260^\circ$	Modified
29	+10	+7 (down)	$0^\circ,120^\circ,240^\circ$	$30^\circ,120^\circ,240^\circ$	Modified
33	0°	-10°(down)	$0^\circ,120^\circ,240^\circ$	$0^\circ,140^\circ,240^\circ$	Modified

- Frequency band 2100 MHz.

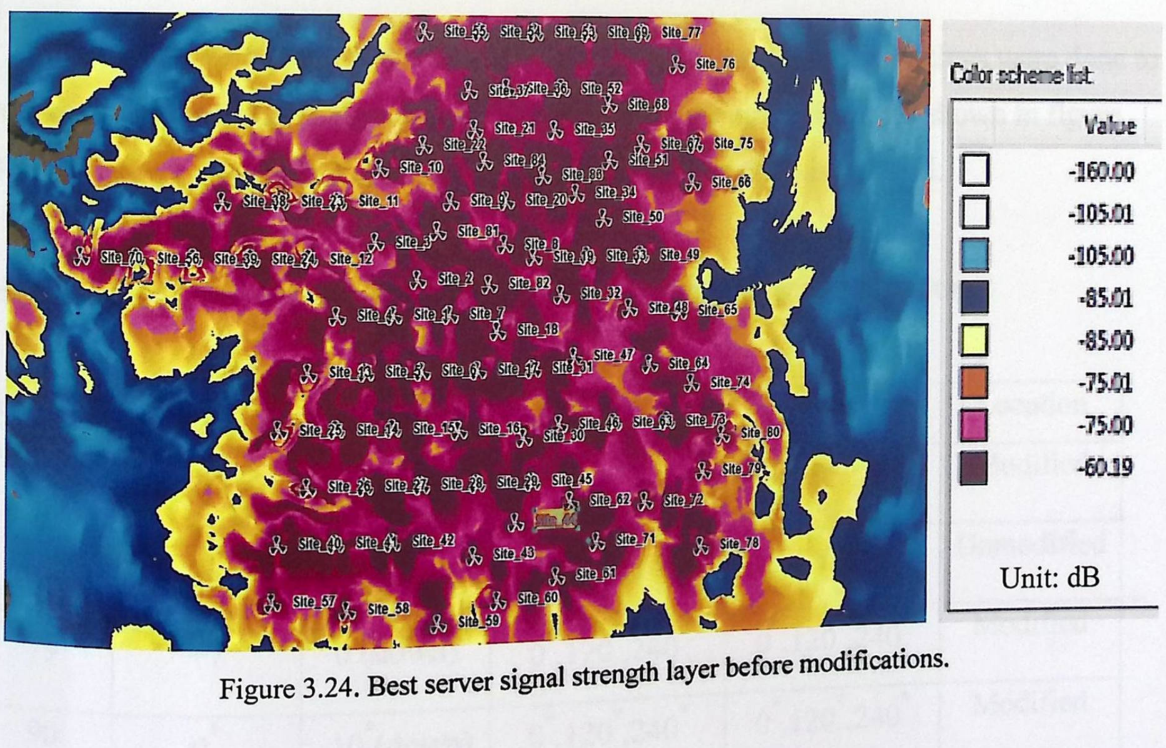


Figure 3.24. Best server signal strength layer before modifications.

The increasing in the frequency band from 1800 MHz to 2100 MHz decreases the signal strength value in some areas from -60 dB to -75 dB. So the 84 sites now is not enough and some modifications are needed.

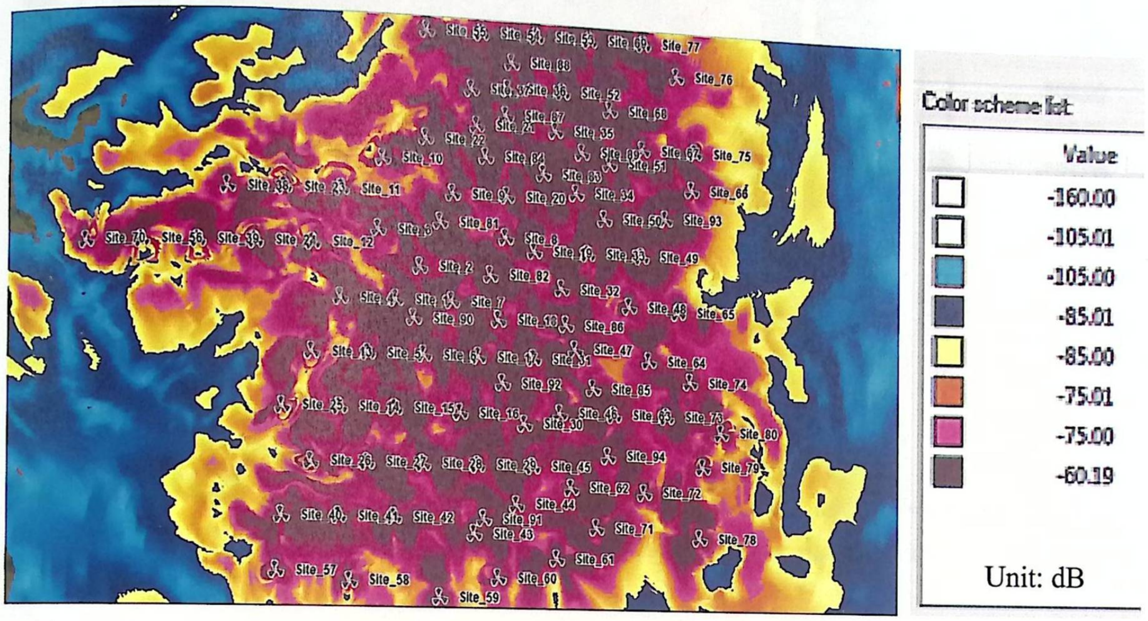


Figure 3.25. Best server signal strength layer after modifications.

Additional 10 sites were added to the area and another modifications were done to recover the decreasing in the signal strength value in some regions. As shown in figure 3.25. the percentage of the area that was covered with -75 dB is reduced.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
35	0°	$+10^\circ$ (up)	$0^\circ,120^\circ,240^\circ$	$0^\circ,120^\circ,240^\circ$	Modified
75	-7°	-10° (down)	$0^\circ,120^\circ,240^\circ$	$0^\circ,120^\circ,250^\circ$	Unmodified
79	+7	0 (down)	$0^\circ,120^\circ,240^\circ$	$0^\circ,120^\circ,240^\circ$	Modified
90	0°	-10° (down)	$0^\circ,120^\circ,240^\circ$	$0^\circ,120^\circ,240^\circ$	Modified

• Frequency band 2600 MHz.

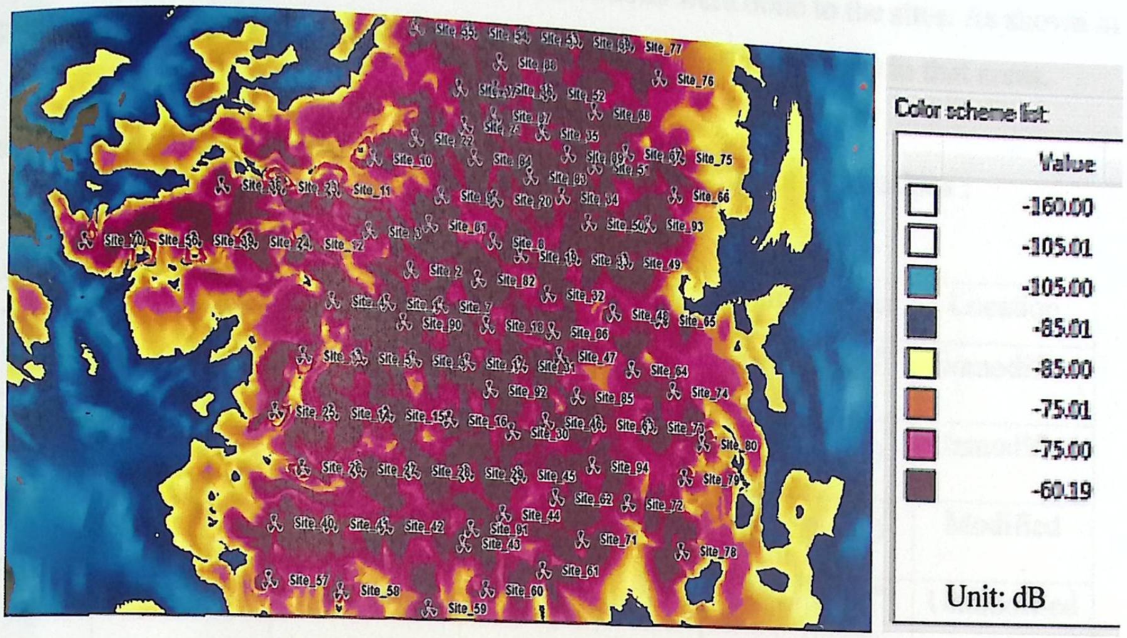


Figure 3.26. Best server signal strength layer before modifications.

94 sites were enough for 2100 MHz frequency band but not yet. Now after the increasing of the frequency band to 2600 MHz, some areas faced a decreasing in the signal strength value.

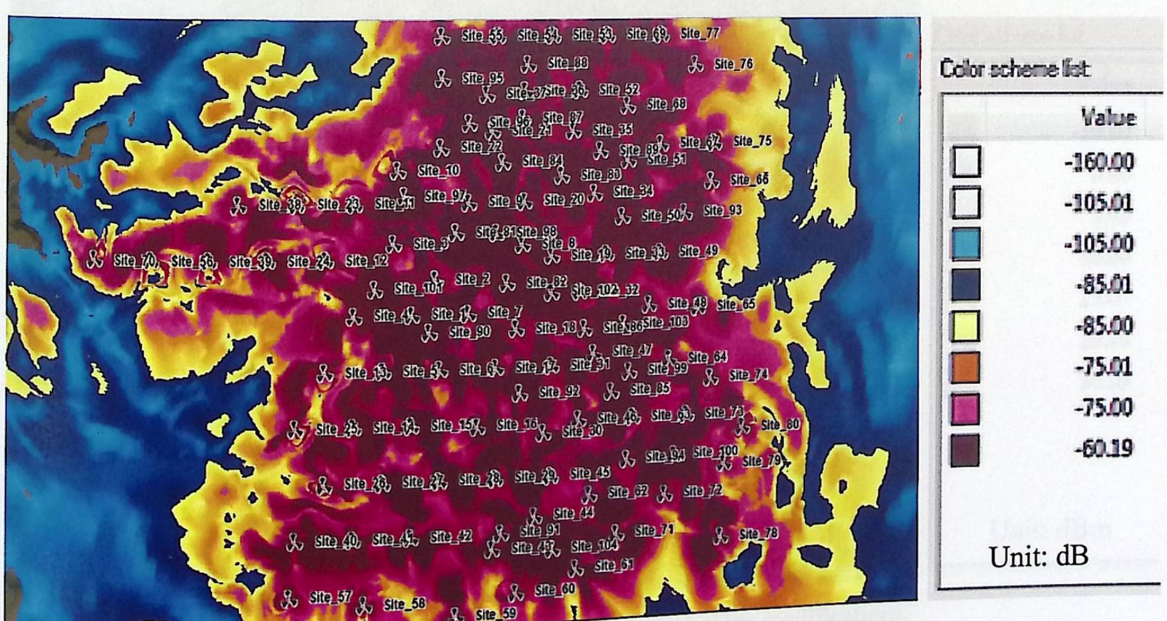


Figure 3.27. Best server signal strength layer after modifications.

To overcome the decreasing in the signal strength value for some areas, additional 10 sites were added and many another modifications were done to the sites. As shown in figure 3.27. the signal strength value increased from -75 dB to -60 dB in that areas.

Here is a sample of the sites that had been modified and their modifications :

Site No.	Tilt before	Tilt after	Azimuth before	Azimuth after	Location
94	-7°	+7° (up)	0°,120°,240°	0°,120°,240°	Unmodified
97	0°	+7° (up)	0°,120°,240°	45°,140°,240°	Unmodified
98	+10°	+7° (down)	0°,120°,240°	30°,160°,240°	Modified
101	0°	-7° (down)	0°,120°,240°	0°,120°,240°	Unmodified

Downlink C over I layer:

- Frequency band 1800 MHz.

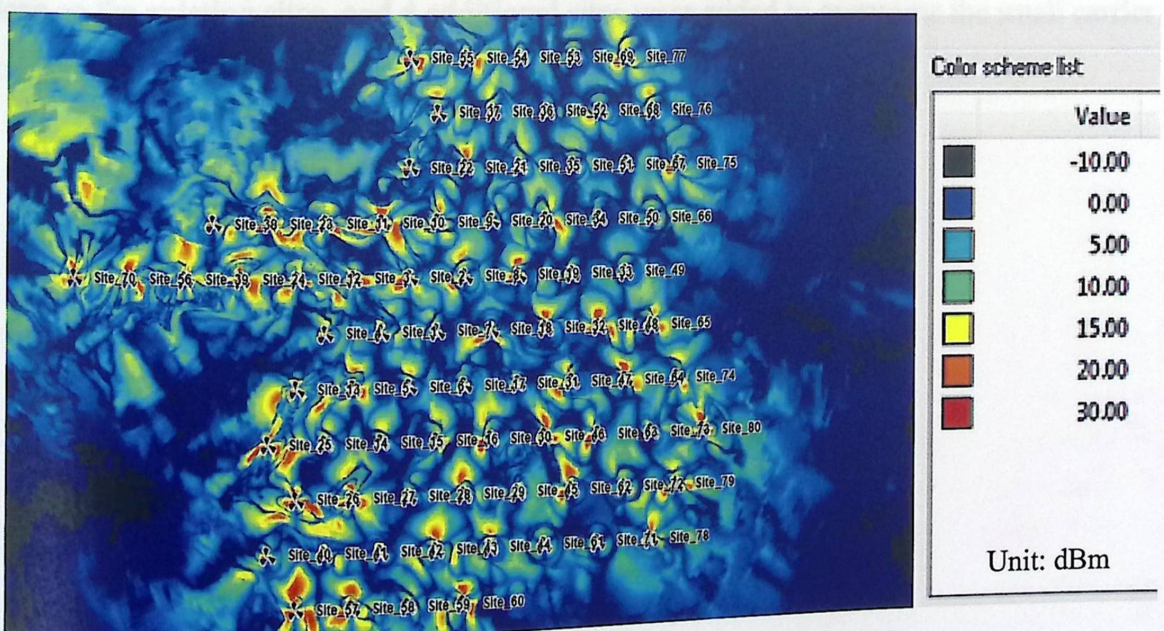


Figure 3.28. Downlink C over I layer before modifications.

For the frequency band 1800 MHz, many regions face high interference (carrier to interference value is 0 dBm), whereas the good carrier to interference value concentrated in smaller areas. So the 80 sites are not enough to provide a good QoS.

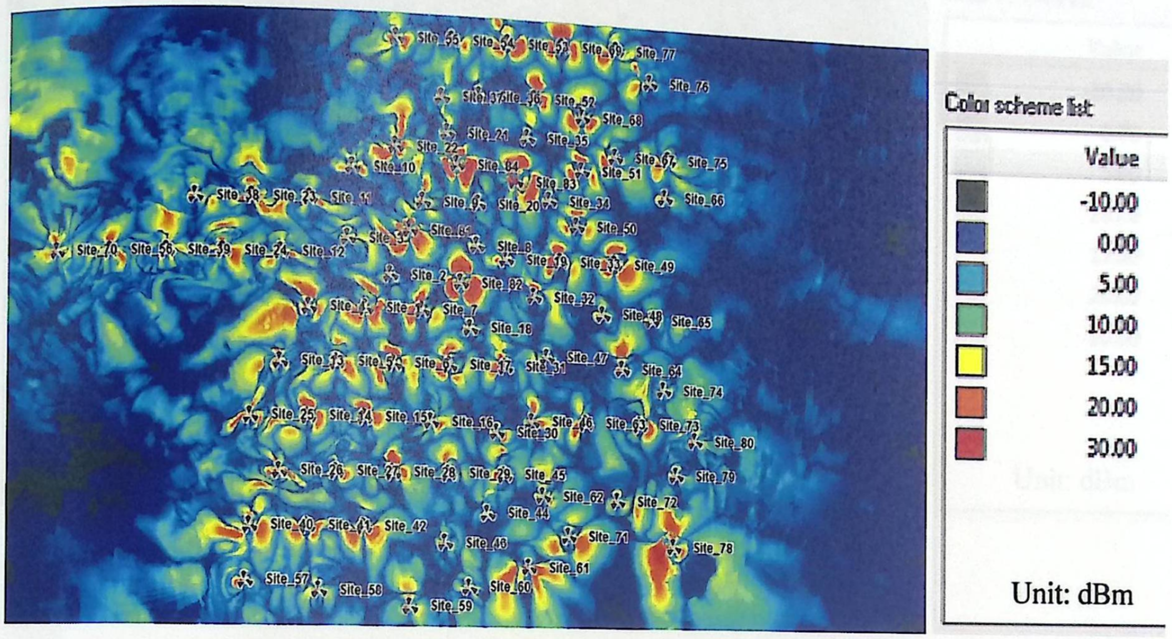


Figure 3.29. Downlink C over I layer after modifications.

Since 80 sites can not provide the area with a good QoS, some modifications were done on the existing sites, and 4 additional sites were added to overcome the small carrier to interference value.

- Frequency band 2100 MHz.

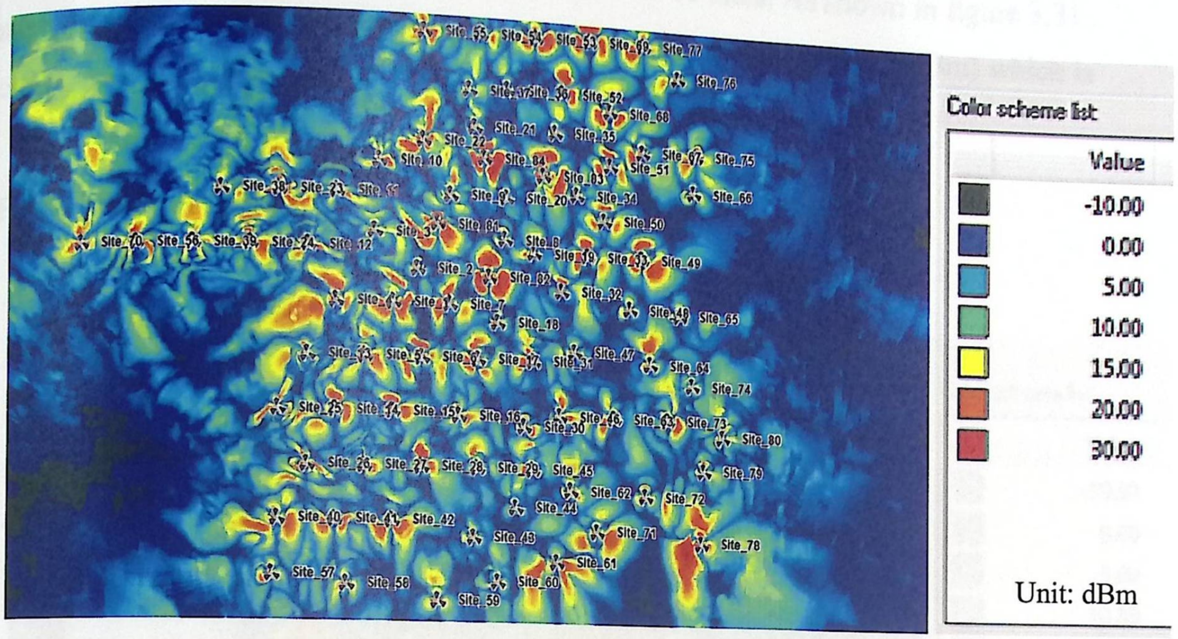


Figure 3.30. Downlink C over I layer before modifications.

After going up to 2100 MHz frequency band, the carrier to interference value decreased, the regions' area that covered with a good carrier to interference value decreased also. So 84 sites were not enough to provide the area with the desired QoS.

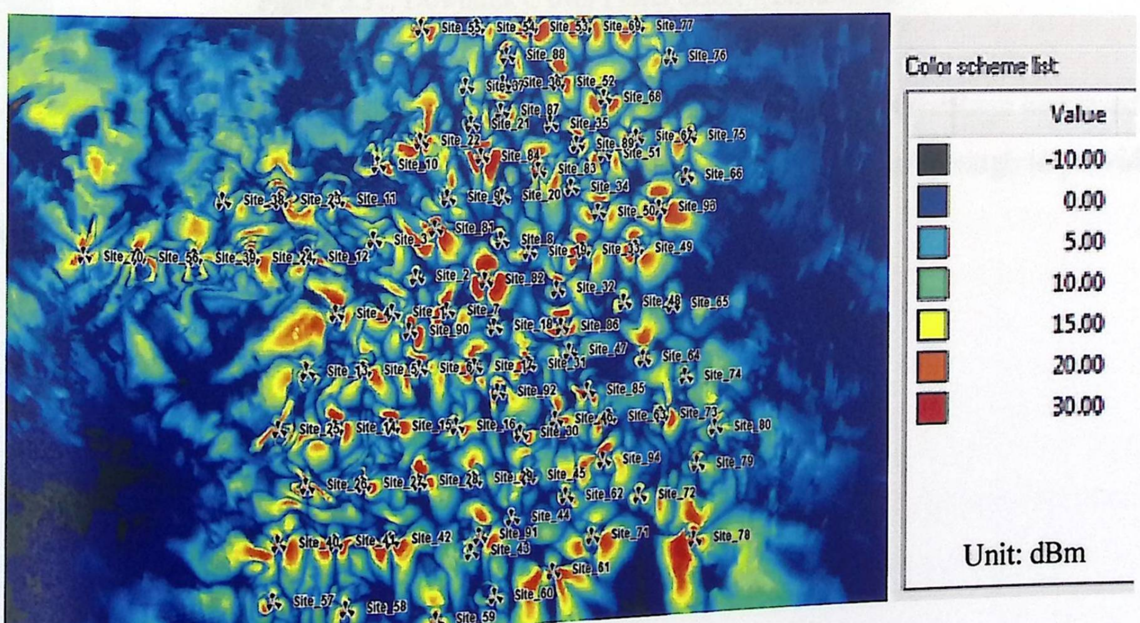


Figure 3.31. Downlink C over I layer after modifications.

Since the 84 sites were not enough to cover the total area with a good carrier to interference value; there was a need for additional 10 sites. As shown in figure 3.31., approximately the total area now is covered by average value (5 ~ 10 dBm) which is considered to be good.

- Frequency band 2600 MHz.

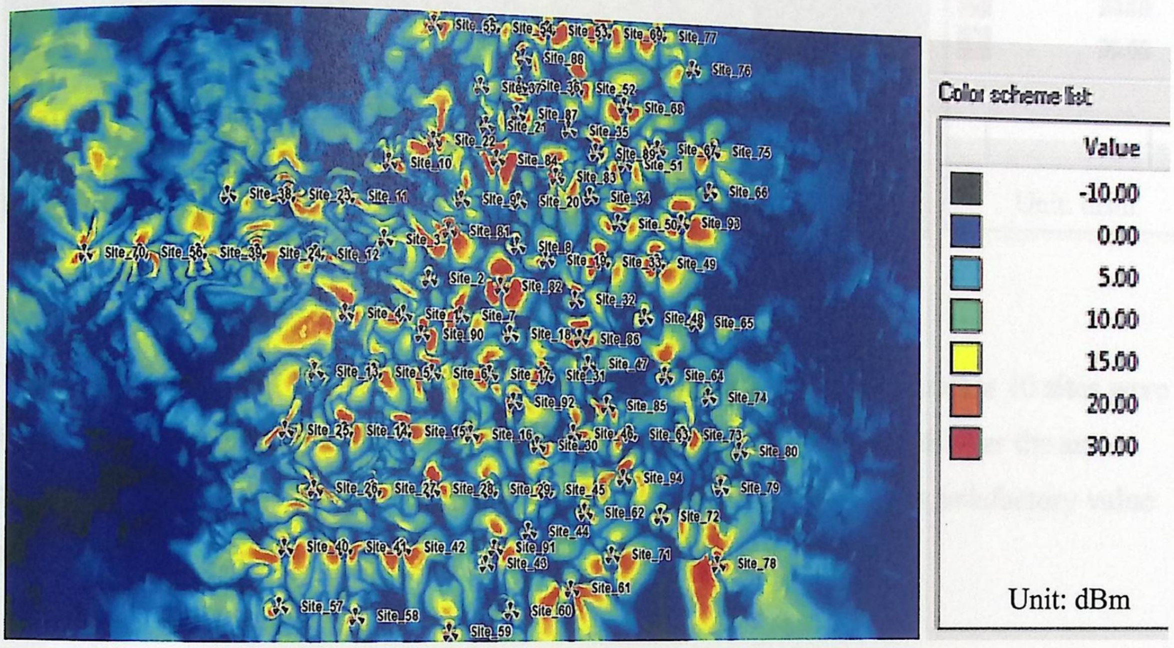


Figure 3.32. Downlink C over I layer before modifications.

After moving to 2600 MHz frequency band, the interference percentage increased in wide areas, this can be noticed in figure 3.32. so the 94 sites were not enough to provide the total area with a good QoS.

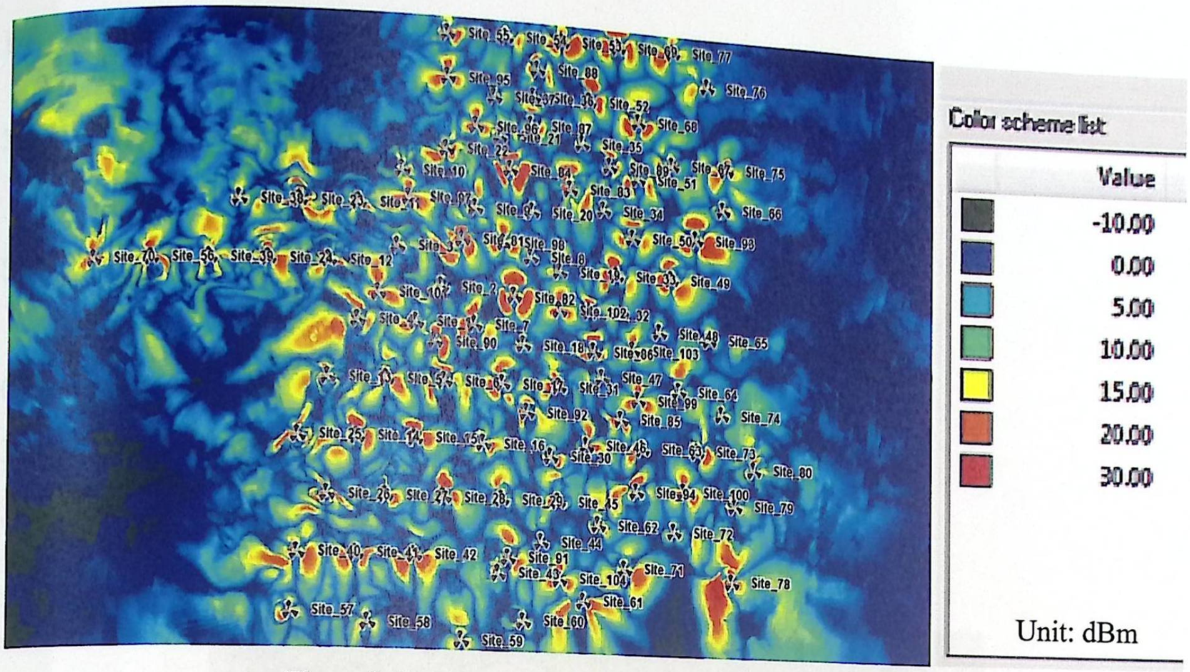


Figure 3.33. Downlink C over I layer after modifications.

To recover the decreasing in the carrier to interference value; another 10 sites were needed. As shown in figure 3.33., the 104 sites that are distributed on all over the area provide an average carrier to interference value about 10 dBm which is satisfactory value of QoS.

3.5.Field Survey

In this plan of Hebron City, there are number of sites that provide a bad coverage and QoS. Many modifications had been carried out on these sites, starting with adjusting the antenna tilt, azimuth, ending with changing the site location. But all these modifications did not affect either the coverage or QoS; so a field survey were needed to solve this problem.

Field survey: to get the real coordinates of the site that suffers from a bad coverage or QoS, then visit it to study the surrounding terrains, buildings and any obstacles that may affect the signals. Then take a decision to solve the problem. The decision may be to change the site location, antenna height…etc.

Here are some sites that were included in the field survey:

3.5.1. WiMAX (3500 MHz) Field Survey

1. Site 26

Coordinates:

35° 5′ 19.89″ long.

31° 30′ 22.76″ lat.

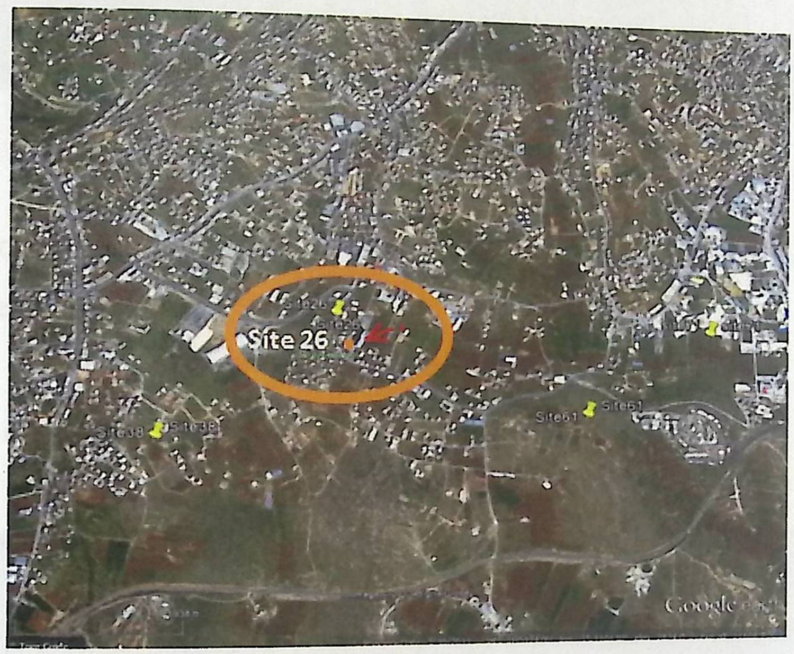


Figure 3.34. Site 26 on Google Earth.

From the coordinates and using Google Earth , site 26 located at south of Hebron (Dahyet Al-Baladyeh). From our visit to the site, we realized that the site located at very low level area and surrounded by many buildings which affect the site's signal strength.

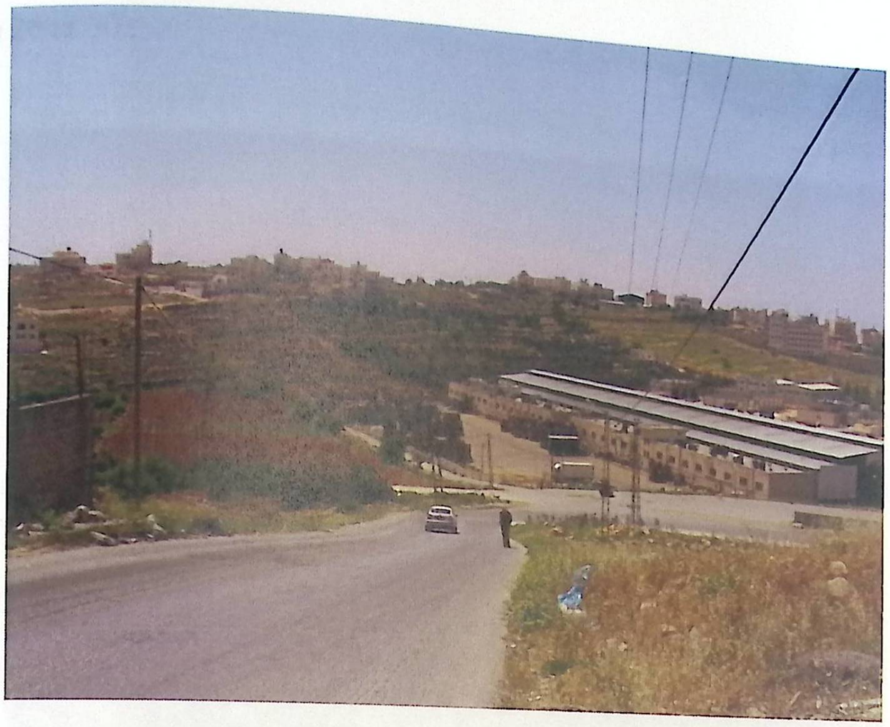


Figure 3.35. Dahyet Al-Baladyeh region.

At the location of site 26, we took a picture to the surrounding terrain and buildings each 30°, and here they are:

1. View of site 26 at 0°.

Figure 3.36. View of site 26 at 0°.

2. View of site 26 at 30°.

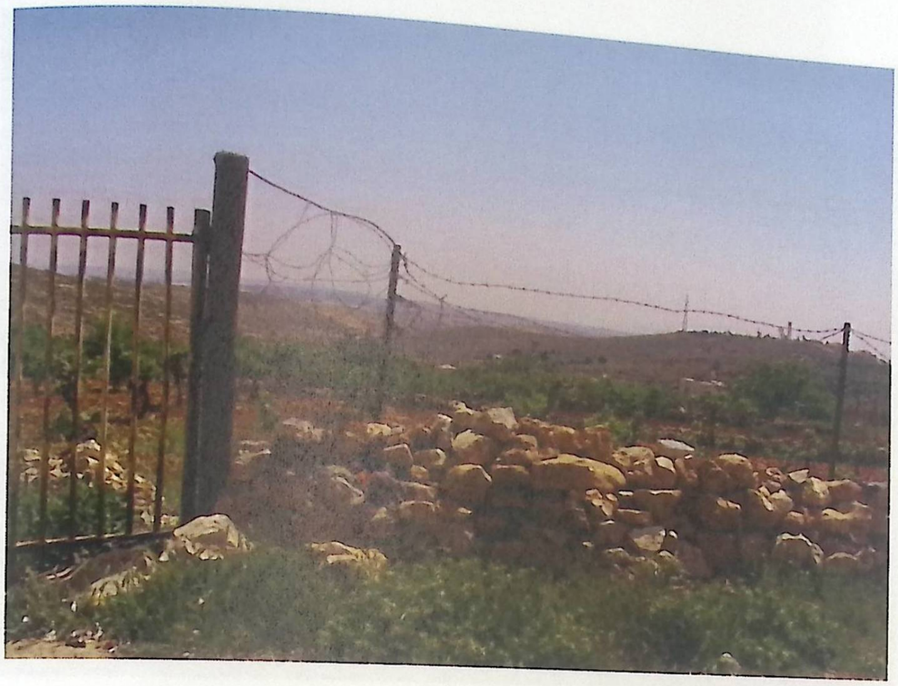


Figure 3.37. View of site 26 at 30°.

3. View of site 26 at 60°.

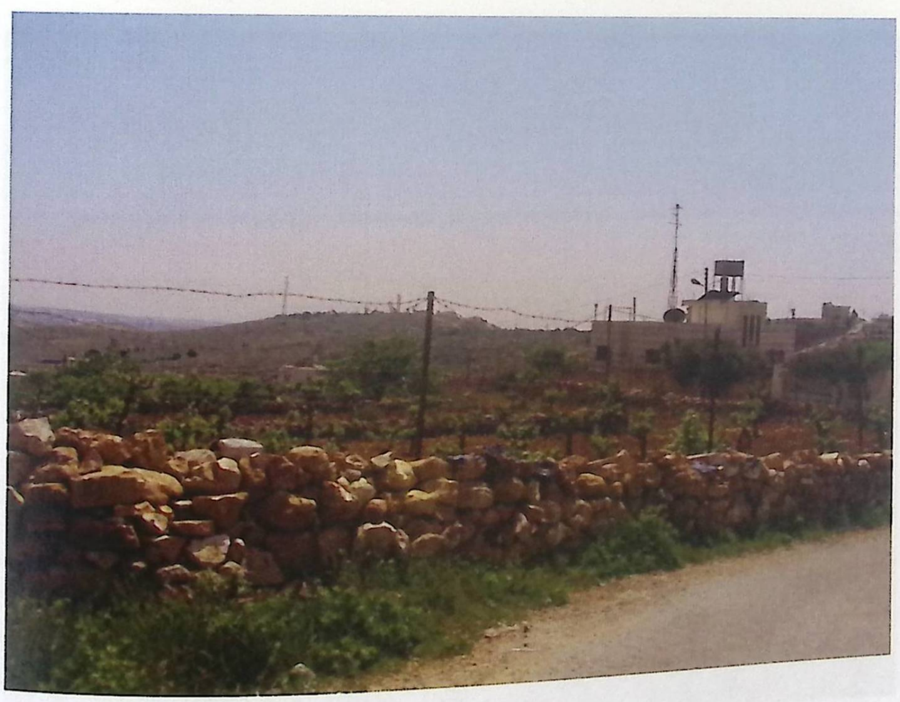


Figure 3.38. View of site 26 at 60°.

4. View of site 26 at 90°.

Figure 3.39. View of site 26 at 90°.

5. View of site 26 at 120°.

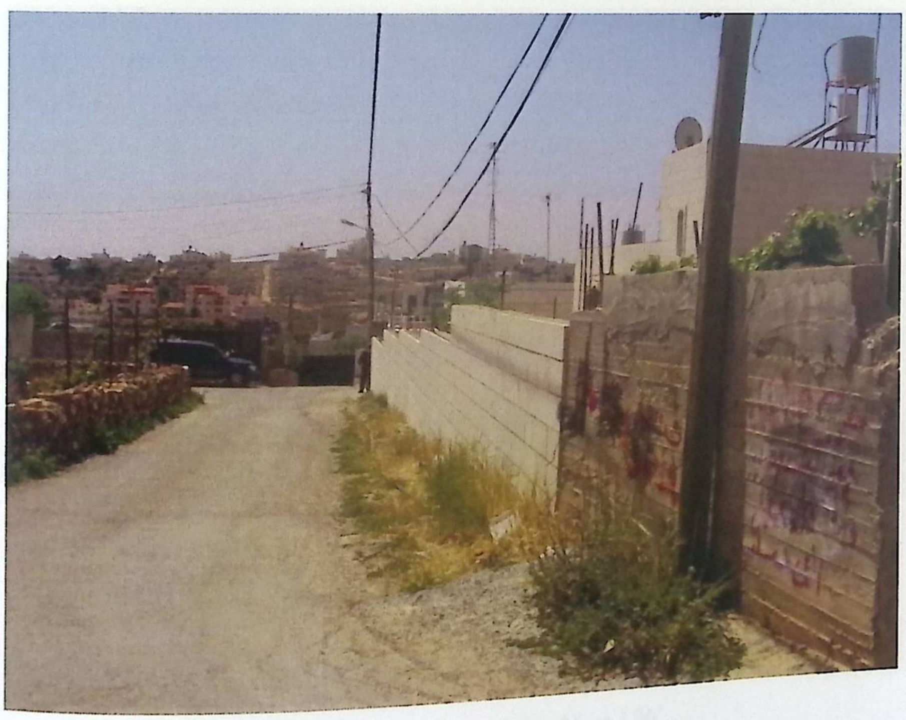


Figure 3.40. View of site 26 at 120°.

6. View of site 26 at 150°.

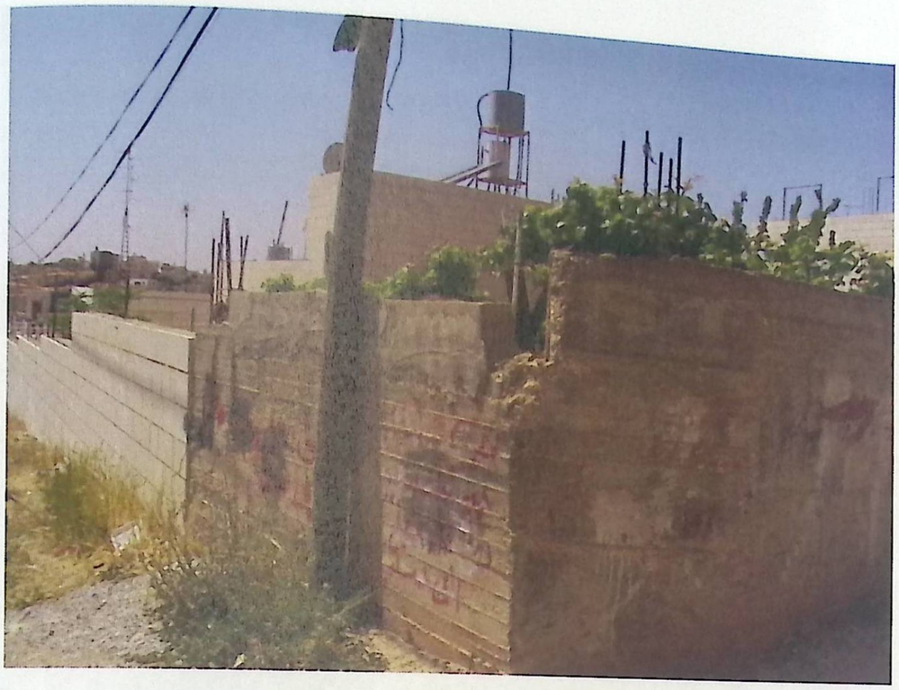


Figure 3.41. View of site 26 at 150°.

7. View of site 26 at 180°.

Figure 3.42. View of site 26 at 180°.

8. View of site 26 at 210˚.

Figure 3.43. View of site 26 at 210˚.

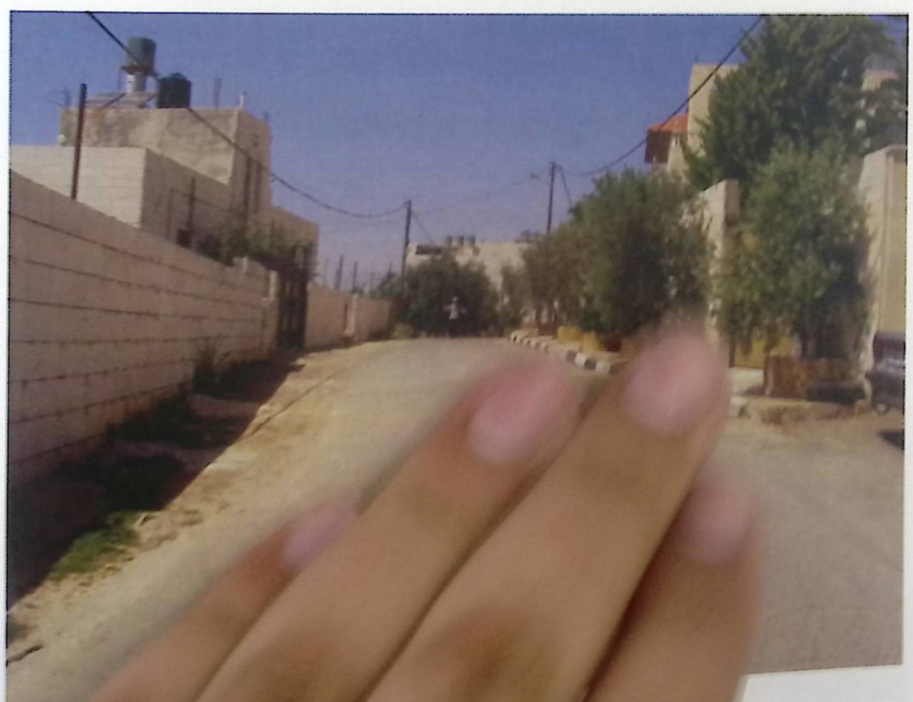
9. View of site 26 at 240˚.

Figure 3.44. View of site 26 at 240˚.

8. View of site 26 at 210°.

Figure 3.43. View of site 26 at 210°.

9. View of site 26 at 240°.



10. View of site 26 at 270°.

Figure 3.45. View of site 26 at 270°.

11. View of site 26 at 300°.

Figure 3.46. View of site 26 at 300°.

12. View of site 26 at 330˚.

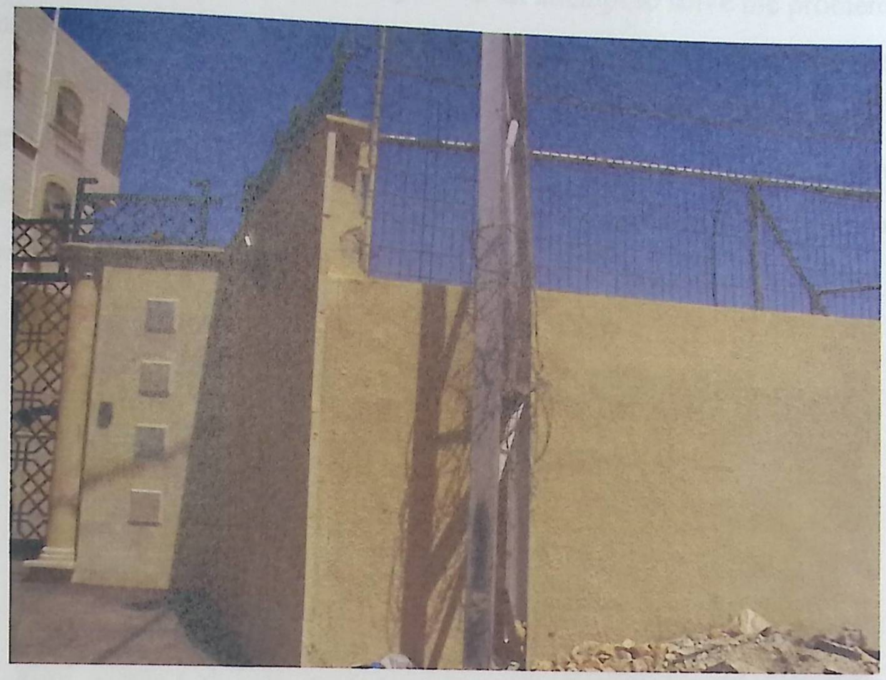


Figure 3.47. View of site 26 at 330˚.

13. View of site 26 at 360˚.

Figure 3.48. View of site 26 at 360˚.

As mentioned above, the site is surrounded by buildings that affect the signal strength. Also it is located at low level region. In an attempt to solve the problem of the low level region and the surrounding buildings, the antenna height was adjusted to be as high as possible but this did not affect too much. So after the field survey, the relocation of the site was an other attempt to improve the carrier to interference value. The new location must be high enough to overlook on areas beyond the surrounding buildings. This new location chosen to be on the roof of Palestine Polytechnic University building (B).

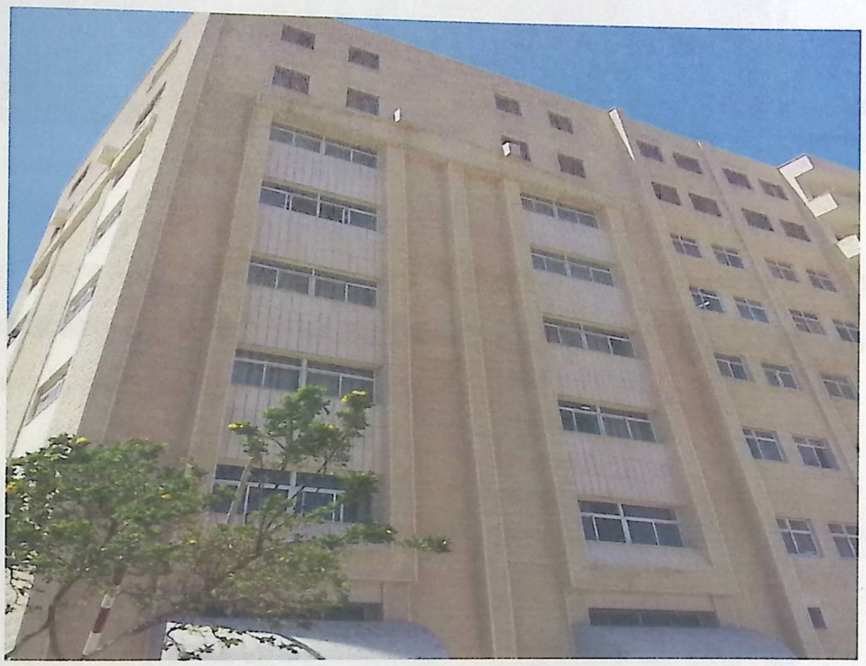


Figure 3.49. The new location of site 26.

The following figures show how the carrier to interference value increased after the relocation:

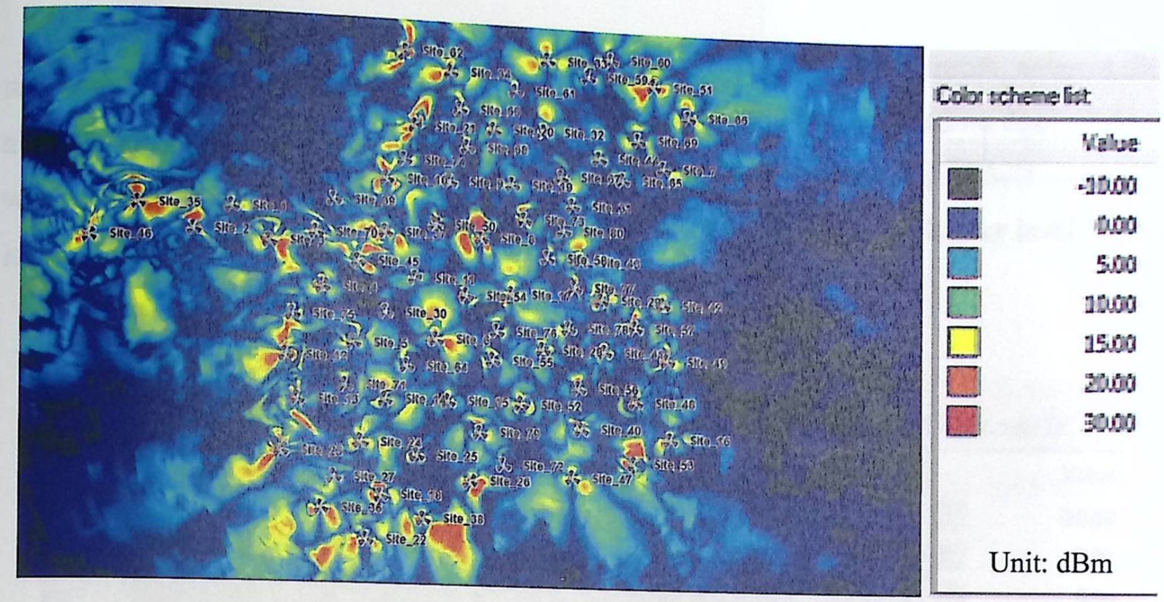


Figure 3.50. Downlink C over I before modifications.

From figure 3.50. the bad carrier to interference value can be noticed clearly. Until now, no modifications had been done yet (neither antenna azimuth, antenna tilt, antenna height, nor site location).

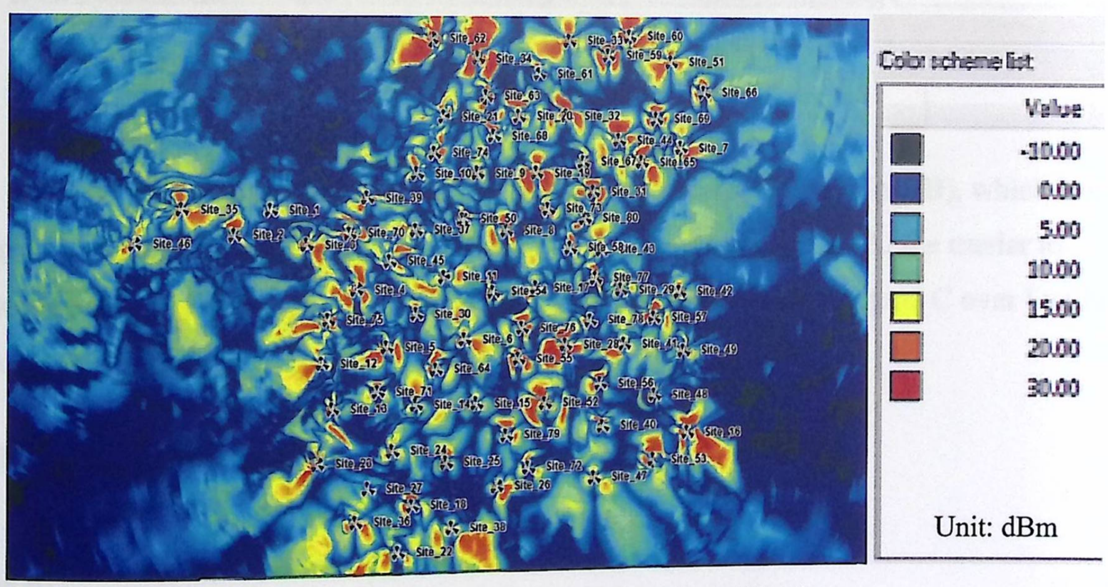


Figure 3.51. Downlink C over I through modifications.
(with no relocation).

Many modifications had been carried out on the site. Antenna azimuth, antenna tilt and antenna height were adjusted and changed many times. But as noticed on figure 3.51. all these attempts did not improve the carrier to interference value never; so field survey was needed. After the field survey, a decision of relocation the site on a higher level region is considered.

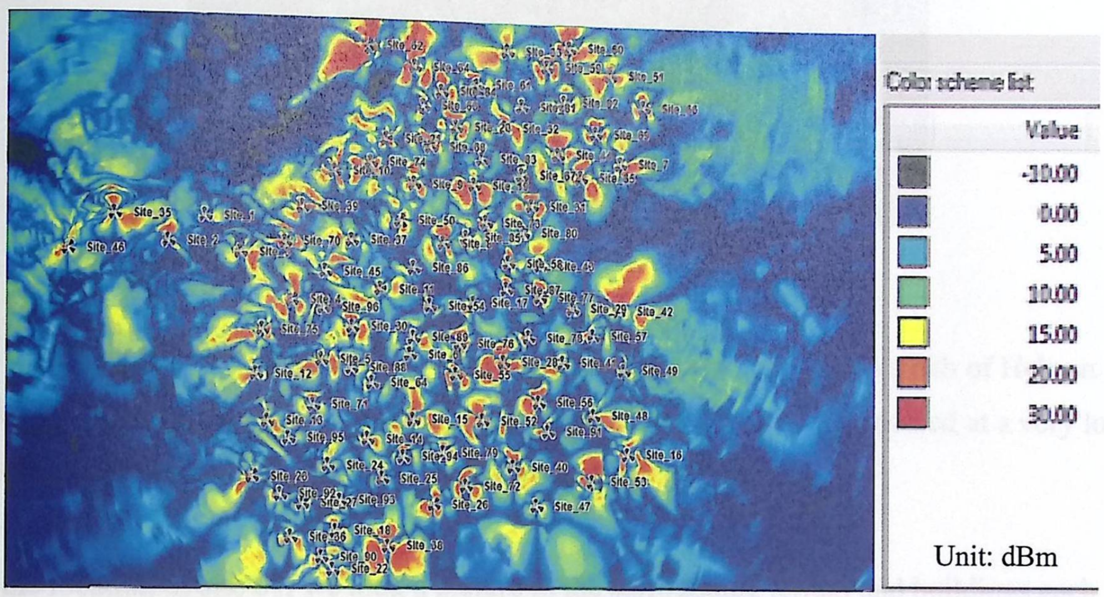


Figure 3.52. Downlink C over I after modifications.
(with relocation).

The site is relocated on Palestine Polytechnic University building (B), which is a higher level region than the previous location. As shown in figure 3.52., the carrier to interference value increased noticeably. The area that covered with a good C over I value becomes larger also.

3.5.2.LTE (1800 MHz) Field Survey

Site 61:

Coordinates:

35° 5′ 57.55″ long.

31° 30′ 9.03″ lat.

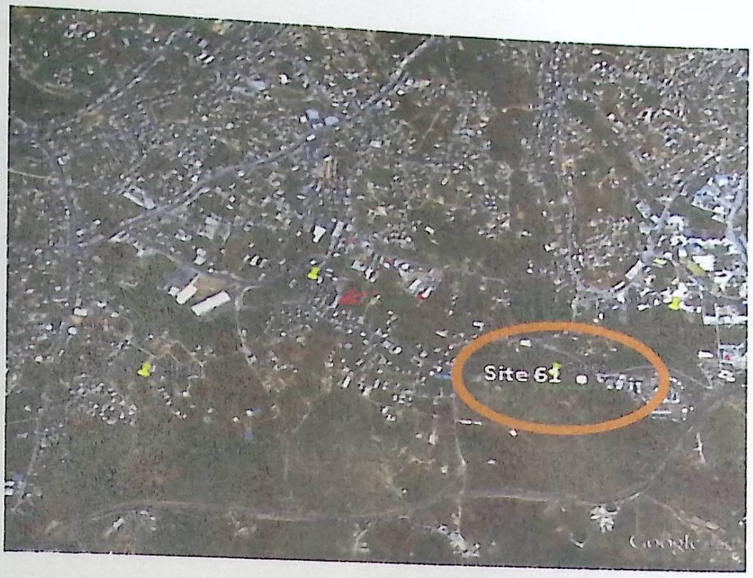


Figure 3.53. Site 61 on Google Earth.

From the coordinates and using Google Earth , site 61 located at south of Hebron (Al-Ertebat region). From our visit to the site, we realized that the site located at a very low level area so the coverage is limited around the site only.

At the location of site 61, we took a picture to the surrounding terrain and buildings each 30°, and here they are:

Figure 3.54. Location of site 61.

1. View of site 61 at 0˚.

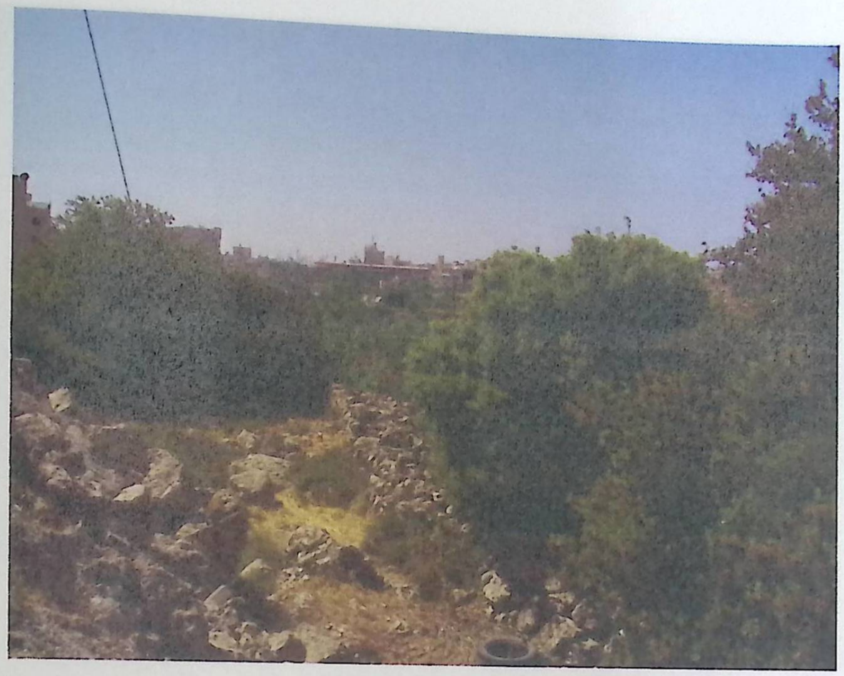


Figure 3.55. View of site 61 at 0˚.

2. View of site 61 at 30˚.

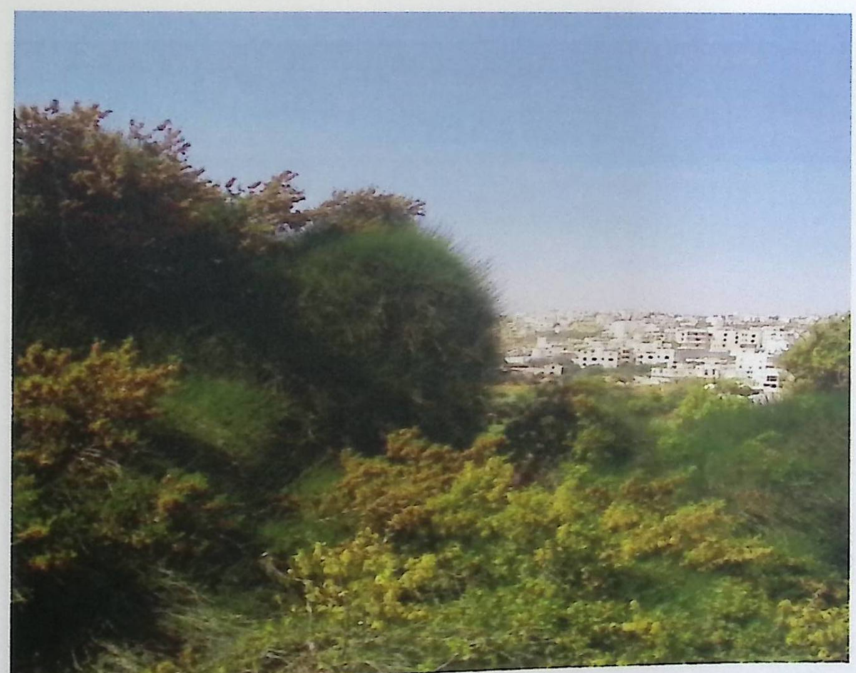


Figure 3.56. View of site 61 at 30˚.

3. View of site 61 at 60˚.

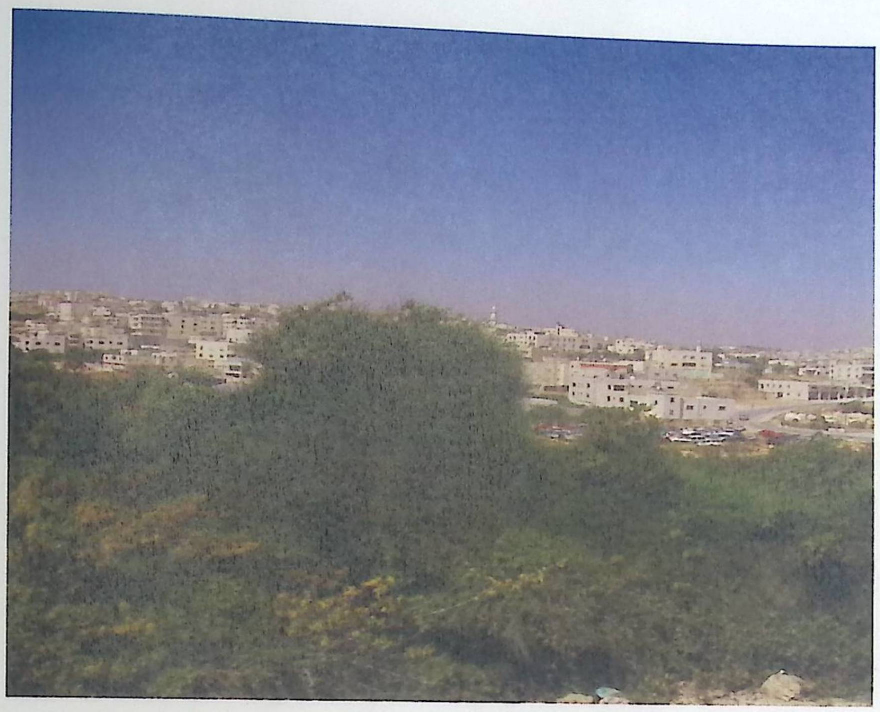


Figure 3.57. View of site 61 at 60˚.

4. View of site 61 at 90˚.

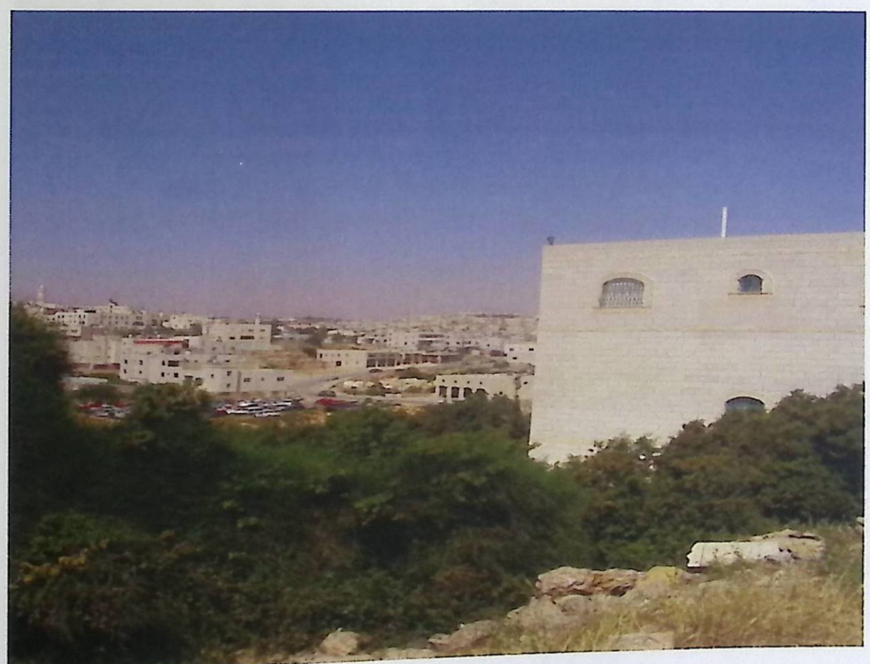


Figure 3.58. View of site 61 at 90˚.

5. View of site 61 at 120°.

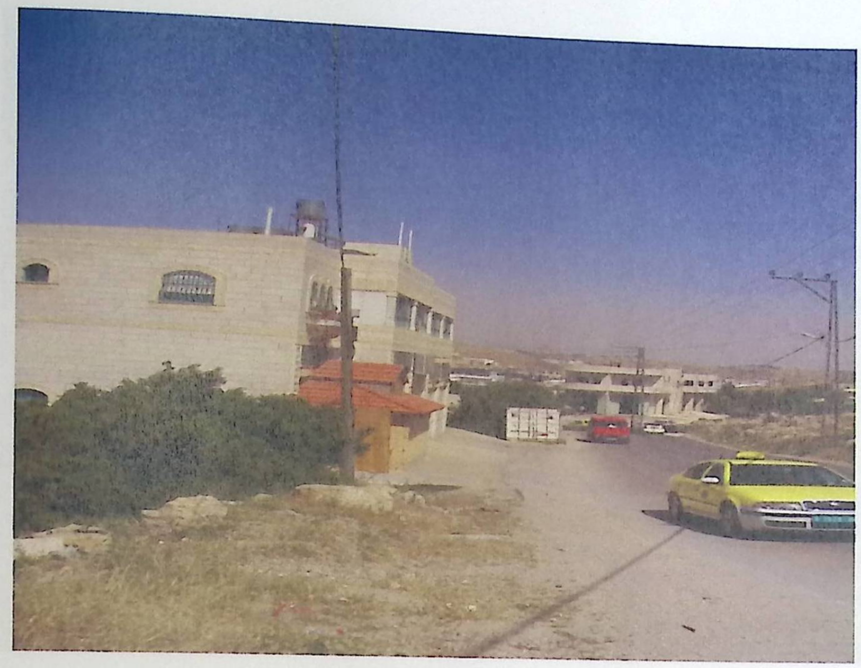


Figure 3.59. View of site 61 at 120°.

6. View of site 61 at 150°.

Figure 3.60. View of site 61 at 150°.

View of site 61 at 180˚.

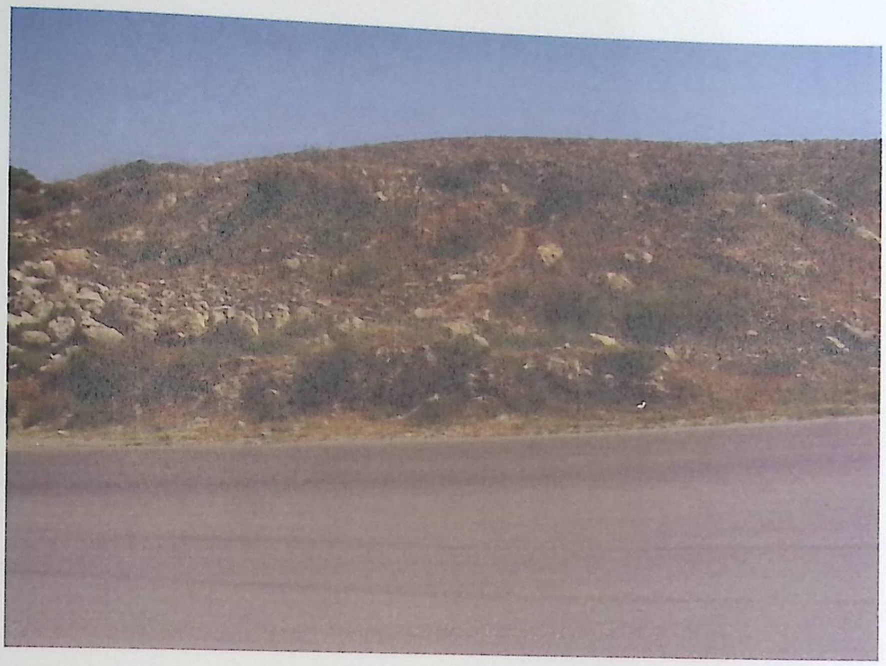


Figure 3.61. View of site 61 at 180˚.

8. View of site 61 at 210˚.

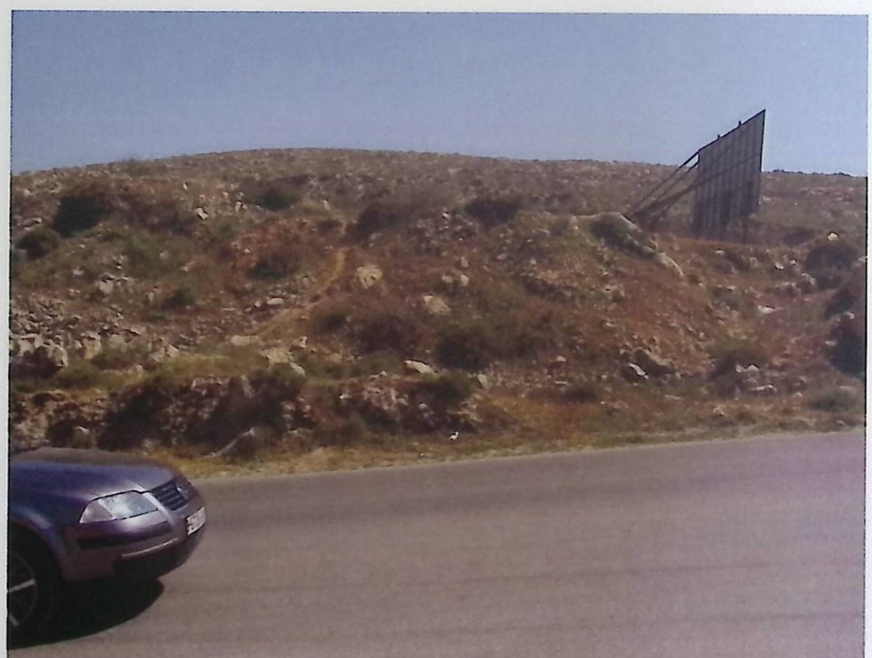


Figure 3.62. View of site 61 at 210˚.

9. View of site 61 at 240˚.

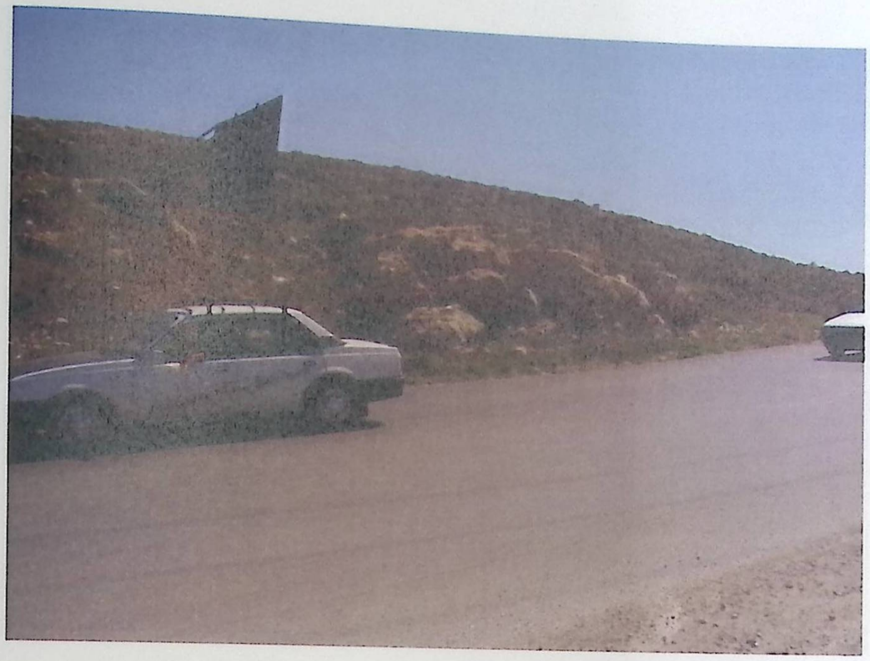


Figure 3.63. View of site 61 at 240˚.

10. View of site 61 at 270˚.

Figure 3.64. View of site 61 at 270˚.

11. View of site 61 at 300˚.

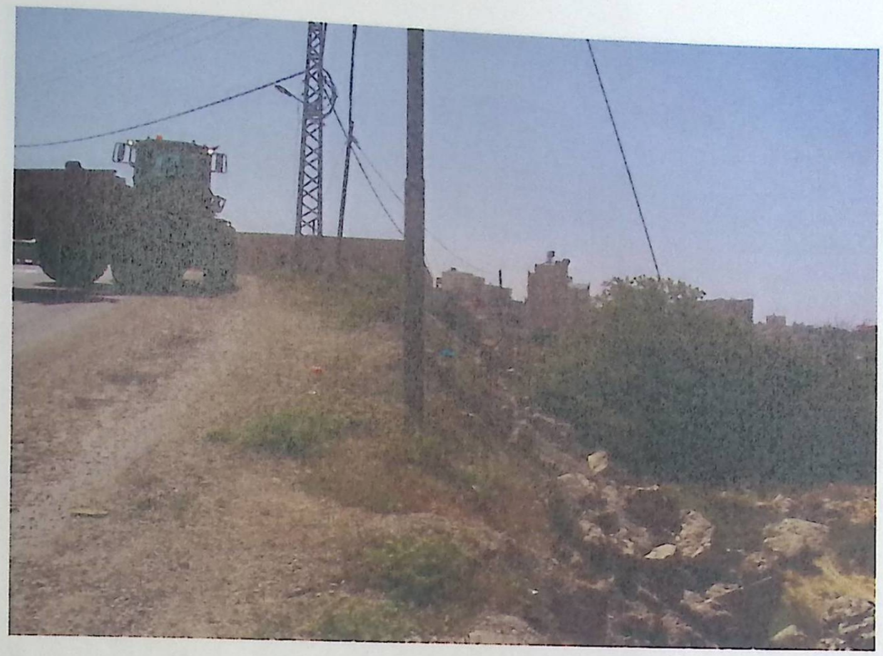


Figure 3.65. View of site 61 at 300˚.

12. View of site 61 at 330˚.

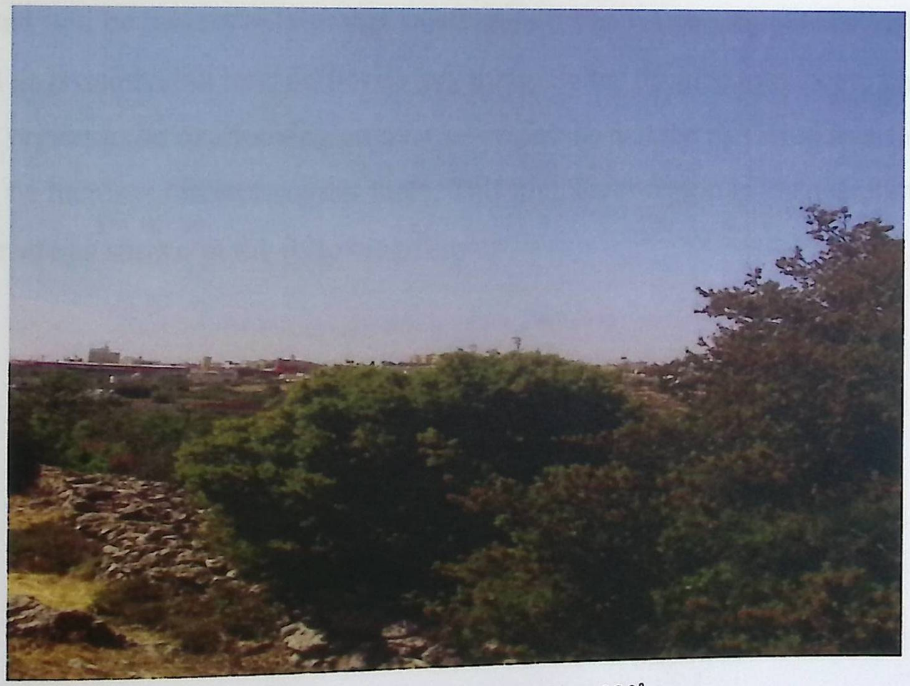


Figure 3.66. View of site 61 at 330˚.

13. View of site 61 at 360˚.

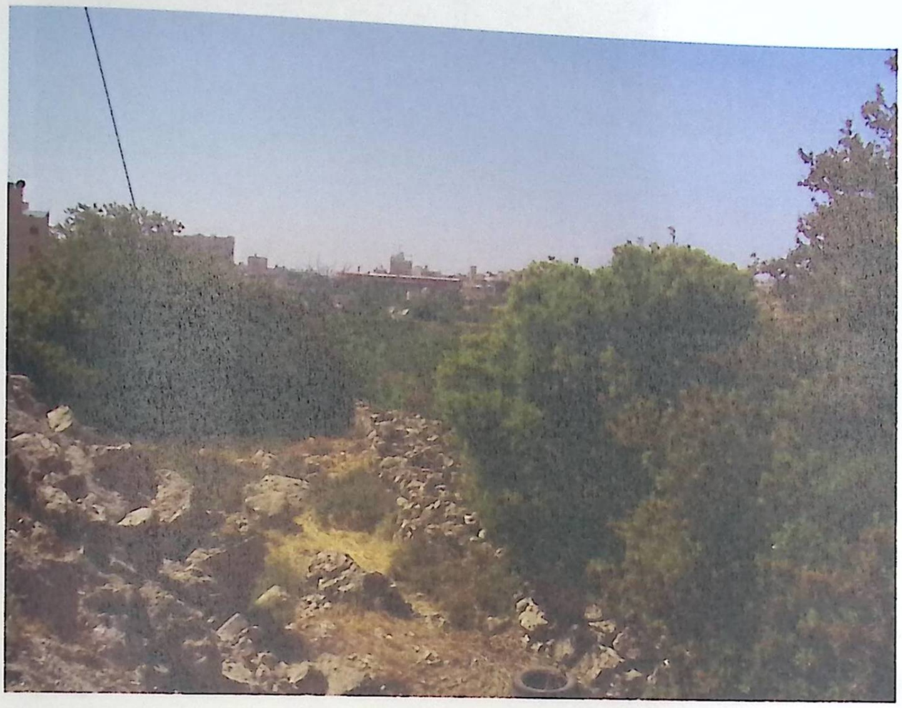


Figure 3.67. View of site 61 at 360˚.

As noticed from the previous figures, the site was located at a very low level region; so the signal will be limited only in that small region. The antenna height was adjusted to be as high as possible, but this did not do any thing. So we decided to relocate the site on a high level region to be overlooking on a larger region so that the carrier to interference value will be increased in many areas there. This high level region is the near mountain behind the site as shown in the following figure:

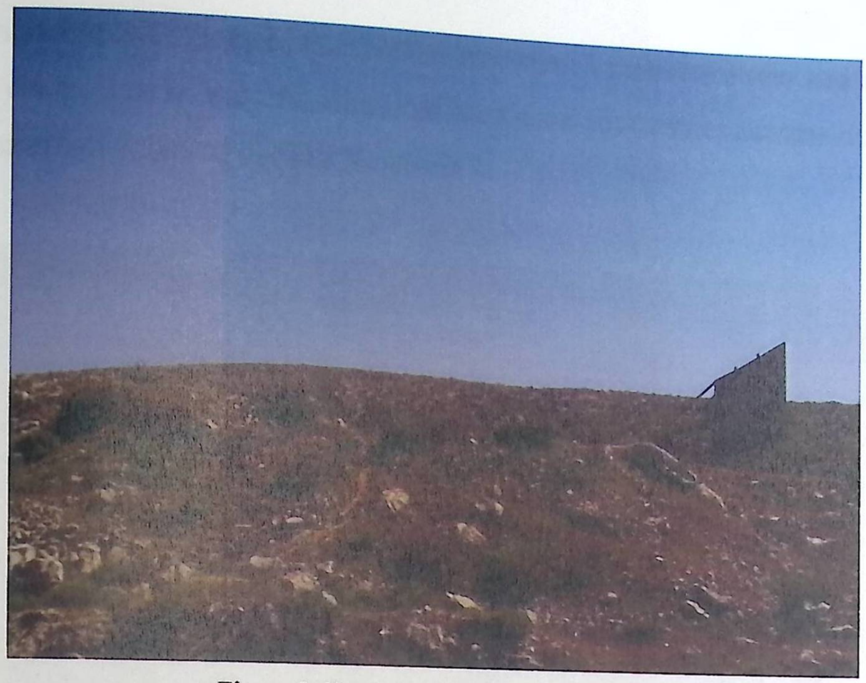


Figure 3.68. The new location of site 61.

The following figures show how the carrier to interference value increased after the relocation:

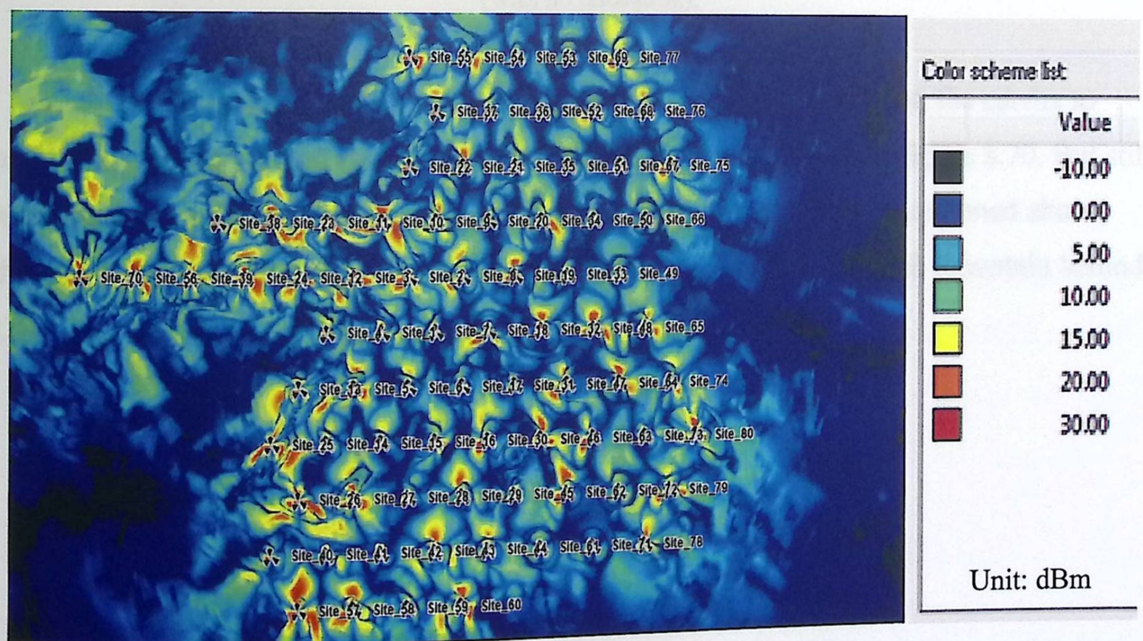


Figure 3.69. Downlink C over I layer before modifications.

It can be noticed clearly in figure 3.69. how site 61 provides a very bad carrier to interference value. Here no modifications had been done yet (neither antenna height, antenna tilt, antenna azimuth, nor site location).

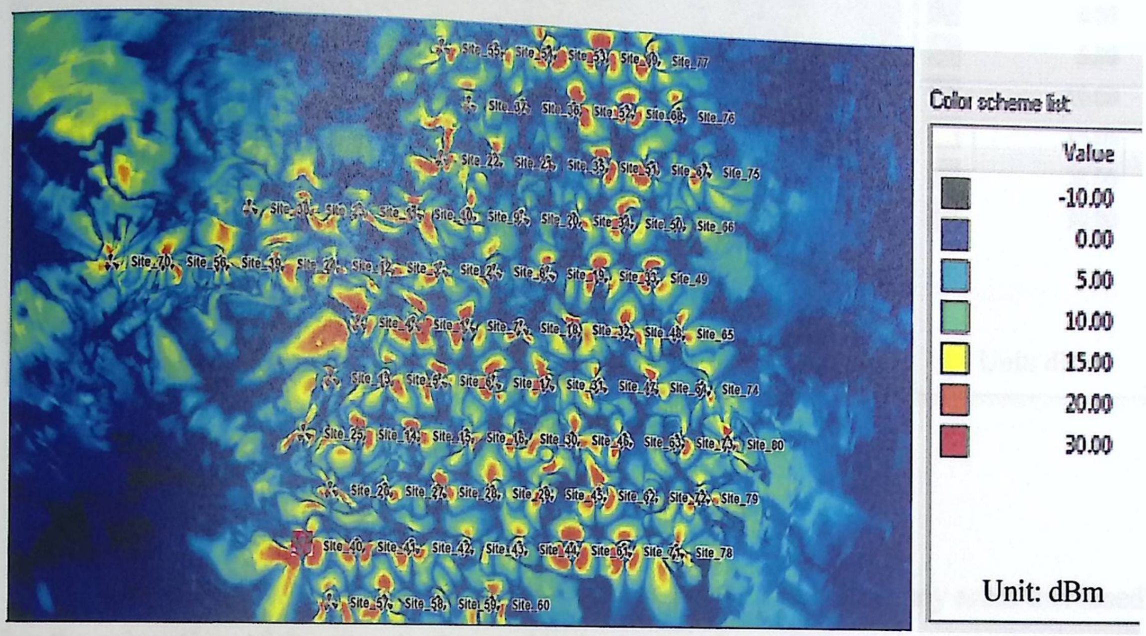


Figure 3.70. Downlink C over I through modifications.
(with no relocation).

After many modifications on the antenna tilt, azimuth and height, the carrier to interference value increased in some areas around the site as shown in figure 3.70. But still there are some areas suffer from low carrier to interference value. As mentioned above, after the field survey for this site, we decide to relocate the site on a high mountain behind it.

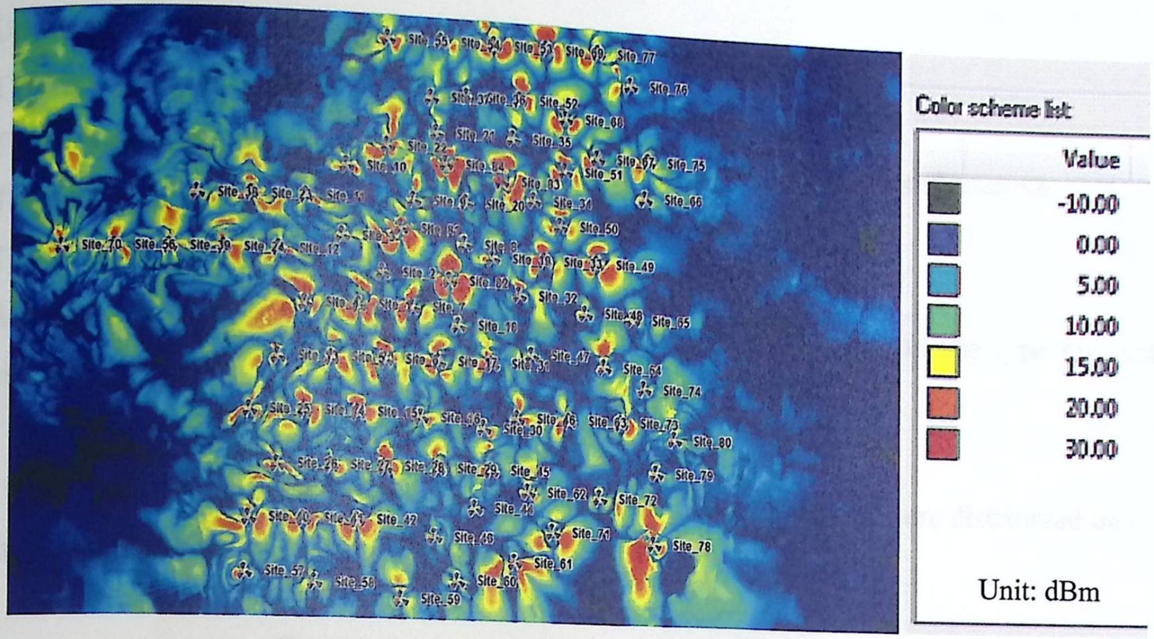


Figure 3.71. Downlink C over I layer after modifications.
(with relocation).

As shown in figure 3.71., the carrier to interference value for many areas increased after the relocation of the site. And now the site is covering wider region with high carrier to interference value than before.

3.6. Sample of WiMAX and LTE planning from the "Introduction To Graduation Project"

In the graduation project, the planning carried out on some different parameters for both WiMAX and LTE technologies. So here some results will be viewed to remind the previous work.

3.6.1.WiMAX Planning Details

There are some important parameters to be adjusted first:

1. The network technology is selected to be WiMAX.
2. This network frequency band is 2600 MHz..

3. One antenna is used for both Tx and Rx (i.e. MIMO is 1x1).
4. TDD used as multiplexing technique.
5. The best antenna type to use is DBXLH-6565C-VTM which is directional antenna.
6. The propagation model is set to be Planet General Model (PGM).
7. The total power (EIRP) is 62.35 dBm.
8. All modulation types here are enabled, the network choose the appropriate type for each user.

Initially, the city was covered with five sites. These five sites were distributed on the most highly density population areas.

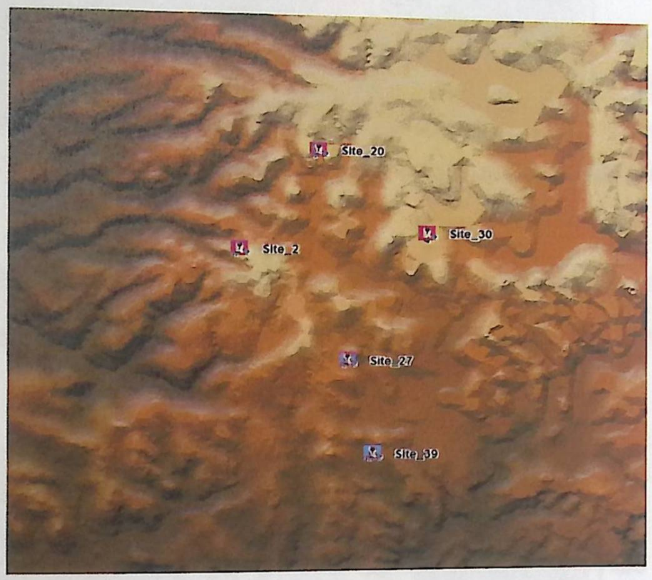


Figure 3.72. Sites location on Hebron map.

Best server signal strength layer (2600 MHz):

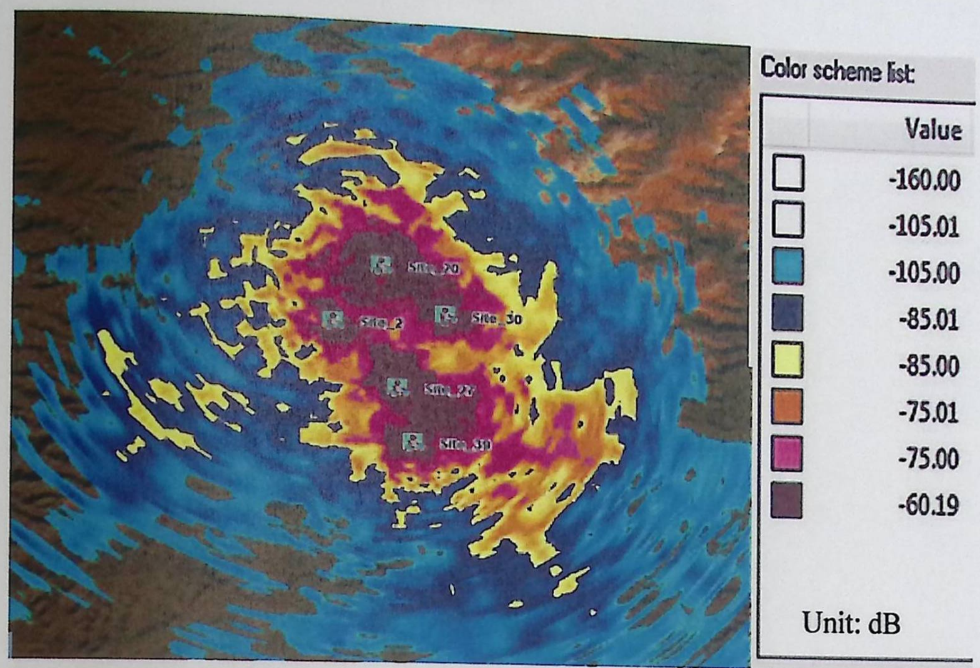


Figure 3.73. Best server signal strength layer before modifications(2600 MHz).

The first view of the best server signal strength layer before any modifications on the sites showed a large area that was not covered by a good signal strength percentage.

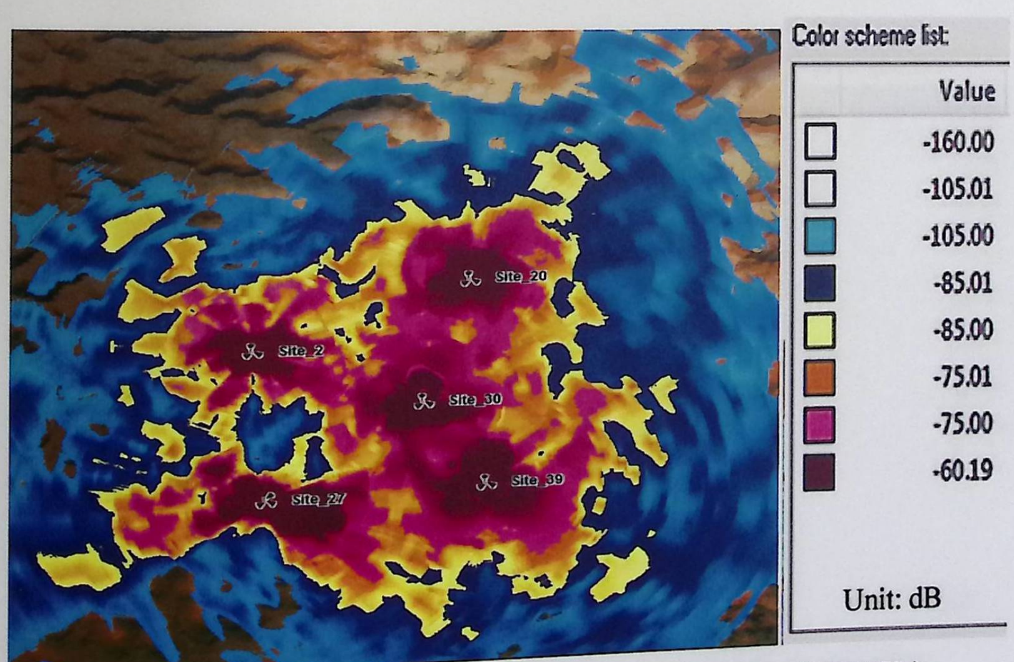


Figure 3.74. Best server signal strength layer after modifications(2600 MHz).

The carried out modifications improved the coverage but did not cover all the area.

Downlink average data rate layer(2600 MHz):

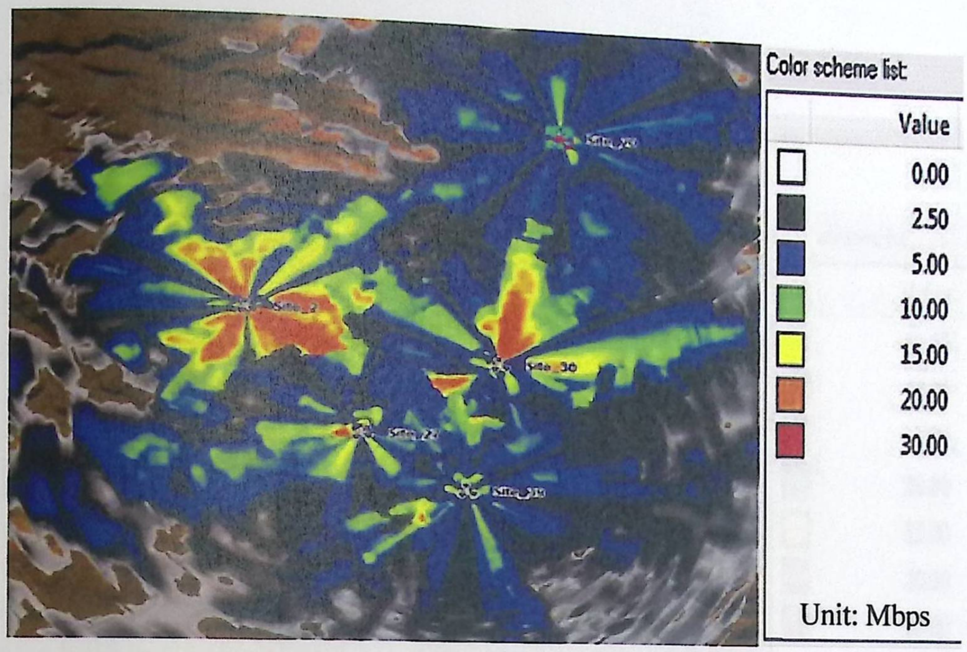


Figure 3.75. Downlink average data rate layer before modifications(2600 MHz).

From figure 3.75. it was clear that all the area nearly had a low downlink average data rate values before any modifications on the sites.

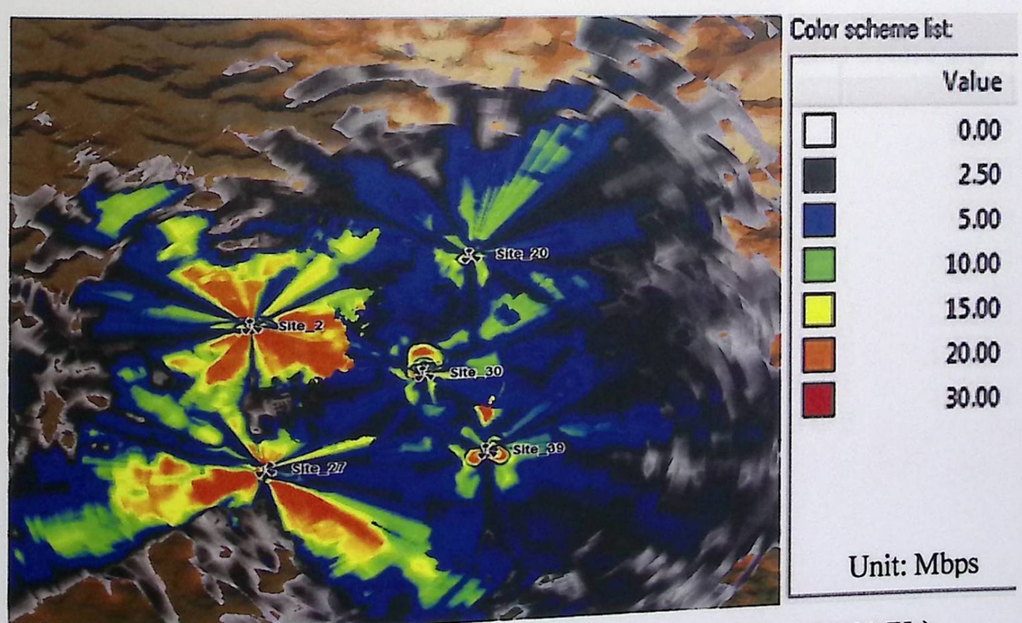


Figure 3.76. Downlink average data rate layer after modifications(2600 MHz).

The performed modifications on the sites increased the value of the downlink average data rate for some small areas, but there was a large area had low downlink average data rate value.

Downlink C/I layer(2600 MHz):

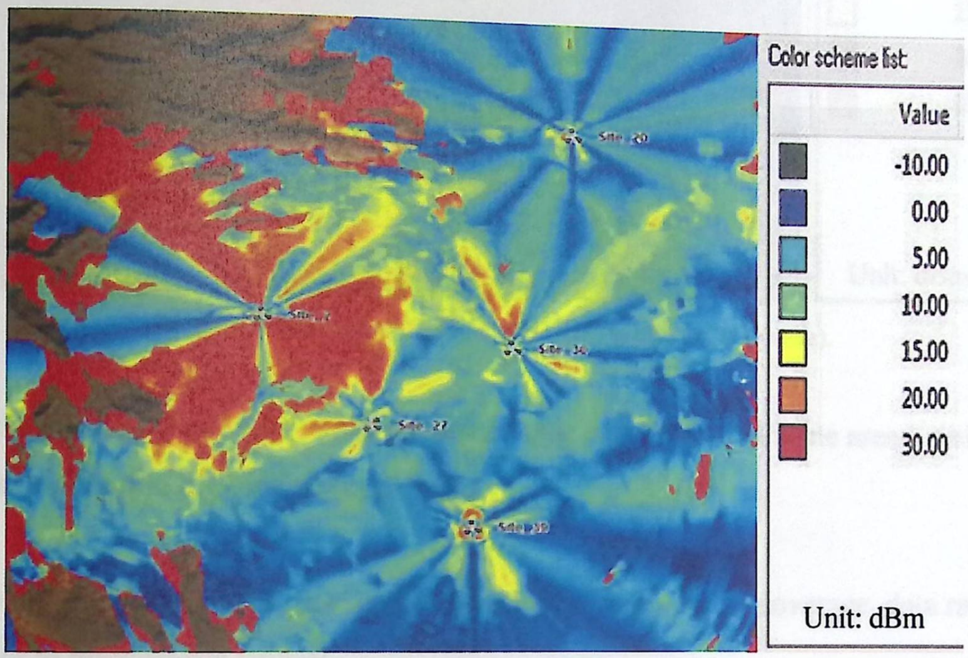


Figure 3.77. Downlink C/I layer before modifications(2600 MHz).

Figure 3.77. showed a large area faced a high interference value before any modifications had been performed.

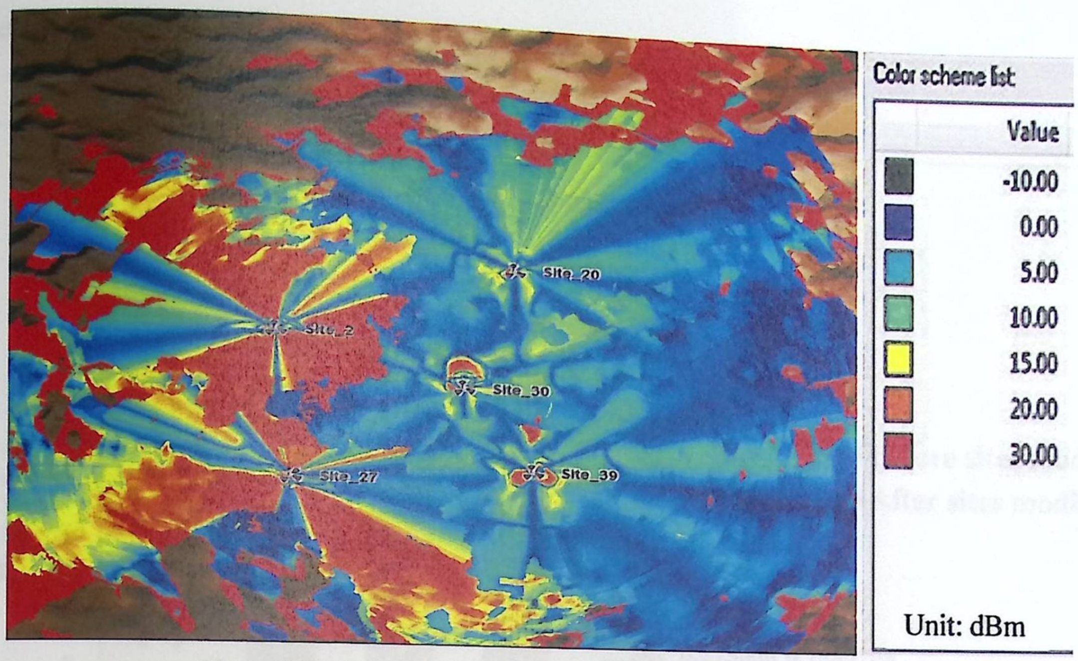


Figure 3.78. Downlink C/I layer after modifications(2600 MHz).

Increasing in the carrier to interference value was noticed in some areas, while other areas was still facing high interference value.

Here is some statistics that showed the improvement in the coverage, data rate and the carrier to interference values:

Best server signal strength layer statistics(2600 MHz):

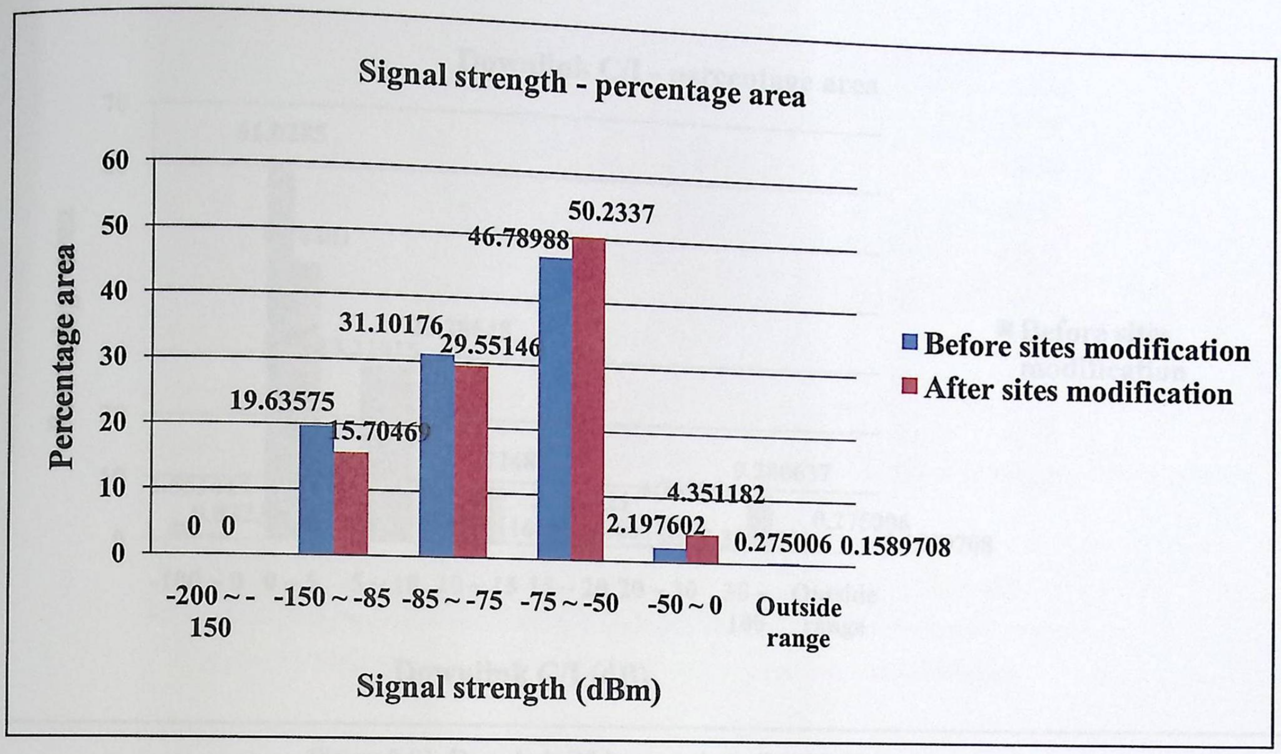


Figure 3.79. Best server signal strength layer statistics(2600 MHz).

Downlink average data rate layer statistics(2600 MHz):

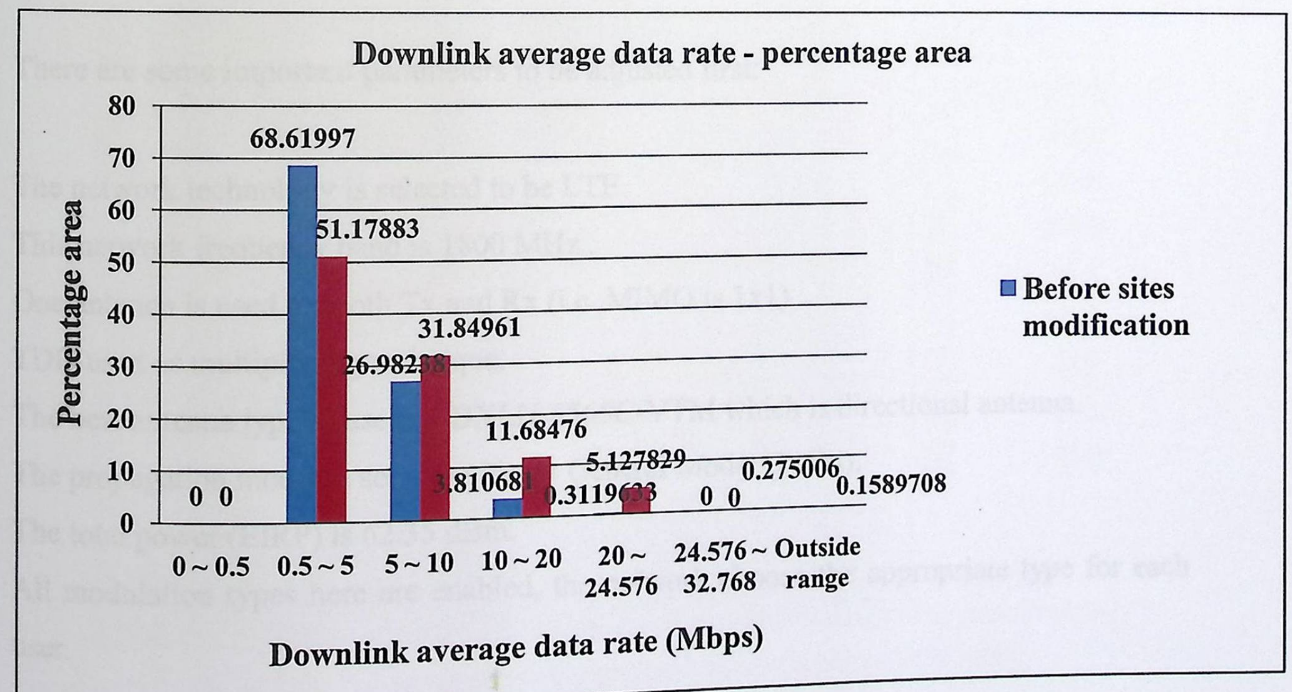


Figure 3.80. Downlink average data rate layer statistics(2600 MHz).

Best server signal strength layer statistics(2600 MHz)

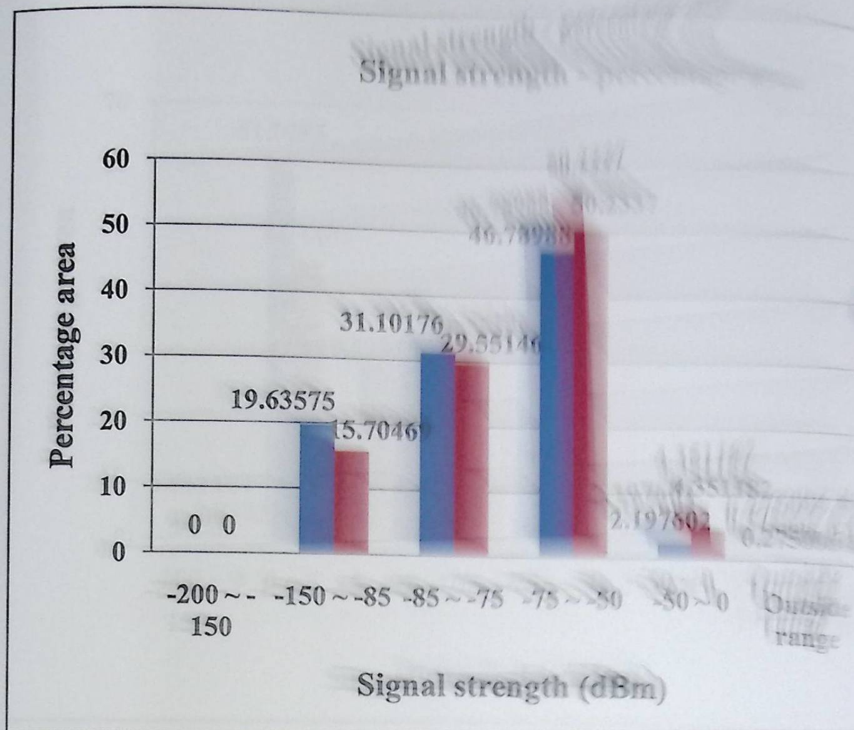


Figure 3.79. Best server signal strength layer statistics(2600 MHz)

Downlink average data rate layer statistics(2600 MHz)

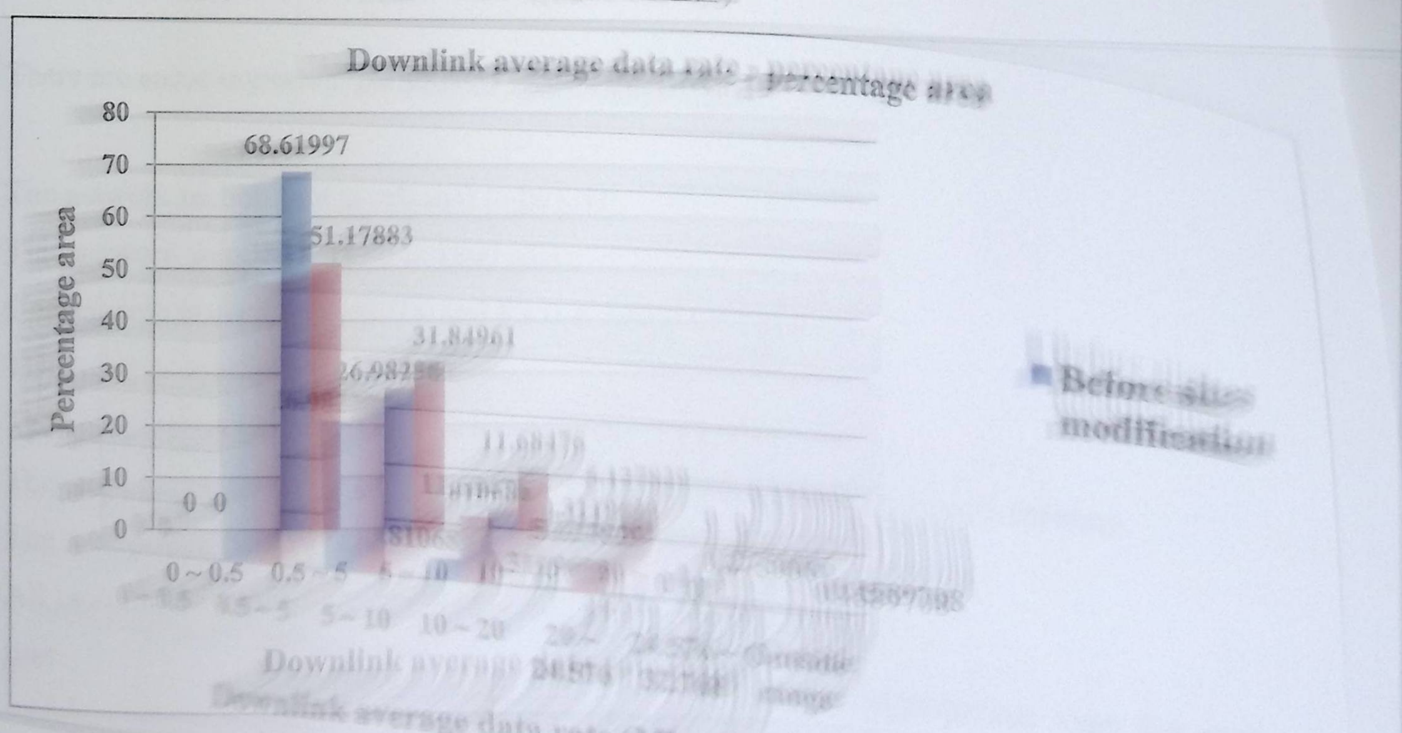


Figure 3.80. Downlink average data rate layer statistics(2600 MHz).

Downlink C/I layer statistics(2600 MHz):

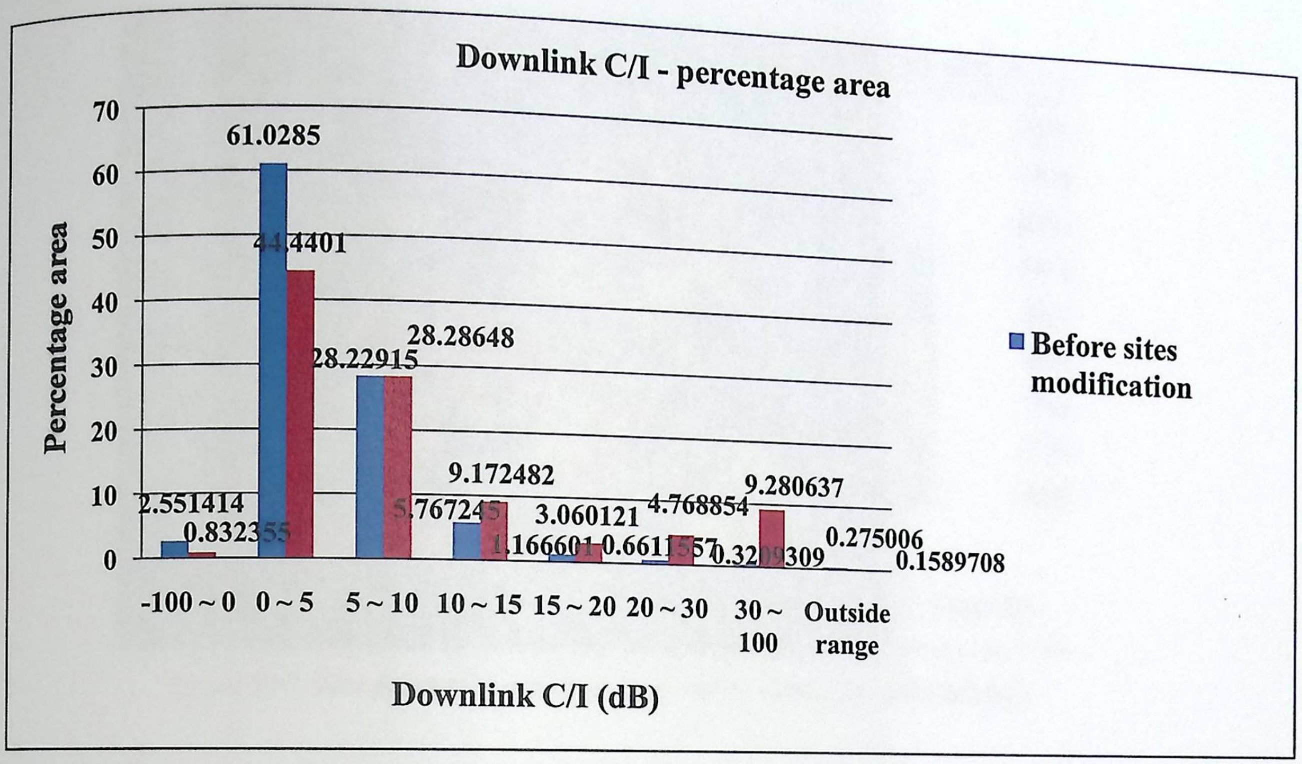


Figure 3.81. Downlink C/I layer statistics(2600 MHz).

3.6.2.LTE Planning Details

There are some important parameters to be adjusted first:

1. The network technology is selected to be LTE.
2. This network frequency band is 1800 MHz..
3. One antenna is used for both Tx and Rx (i.e. MIMO is 1x1).
4. TDD used as multiplexing technique.
5. The best antenna type to use is DBXLH-6565C-VTM which is directional antenna.
6. The propagation model is set to be Planet General Model (PGM).
7. The total power (EIRP) is 62.35 dBm.
8. All modulation types here are enabled, the network choose the appropriate type for each user.

Best server signal strength layer(1800 MHz):

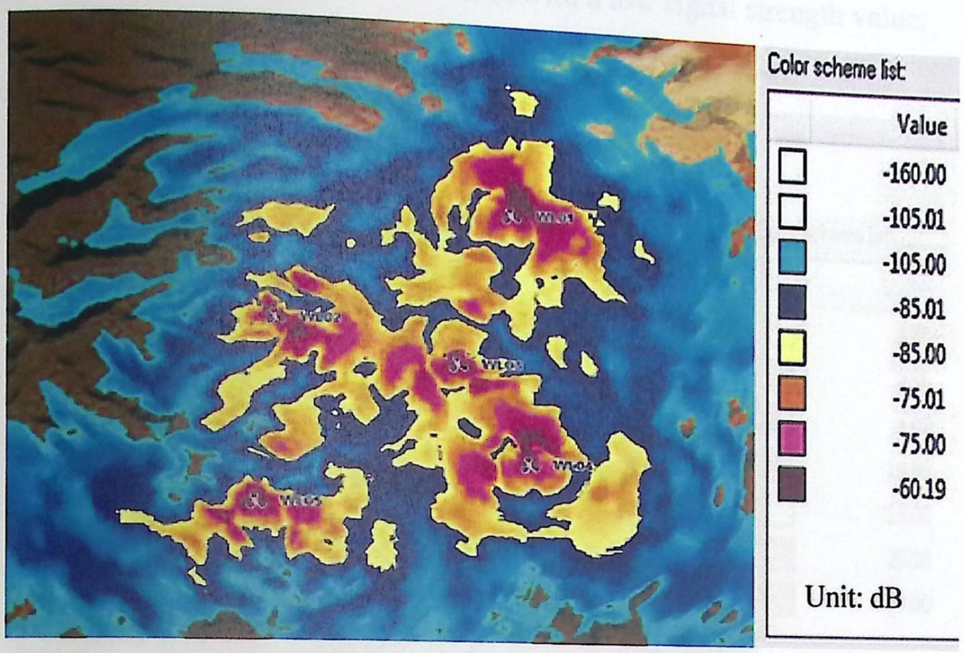


Figure 3.82. Best server signal strength layer before modifications(1800 MHz).

Before any modifications on the sites, it was noticed that there was a large area had low signal strength value.

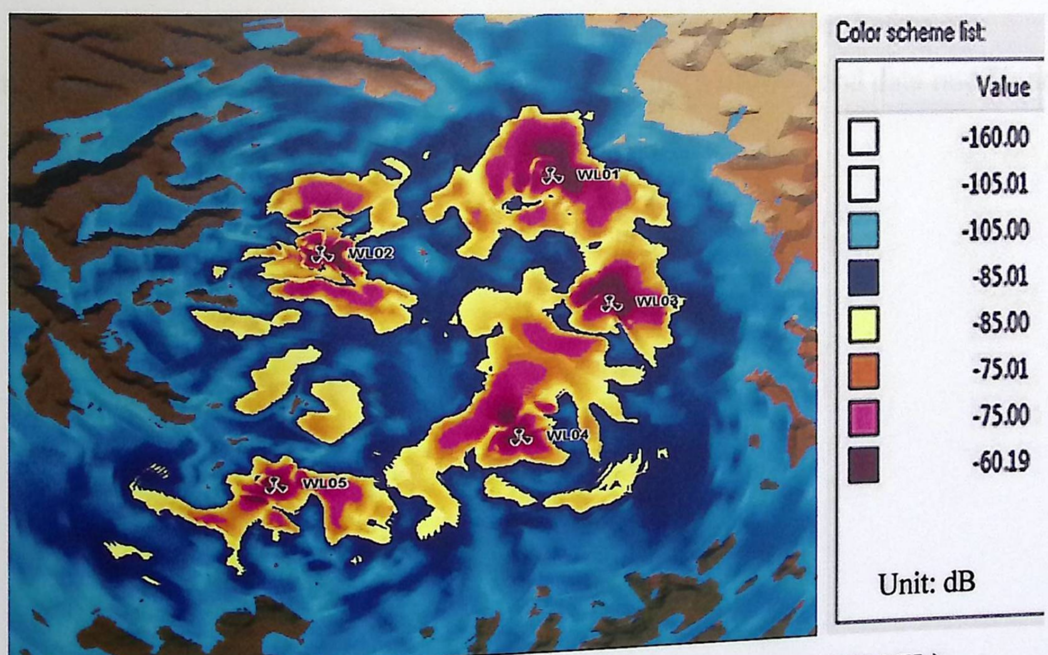


Figure 3.83. Best server signal strength layer after modifications(1800 MHz).

Figure 3.83. showed the improvement in the signal strength value in some areas clearly. But there was also a large area covered with a low signal strength value.

Downlink average data rate layer(1800 MHz):

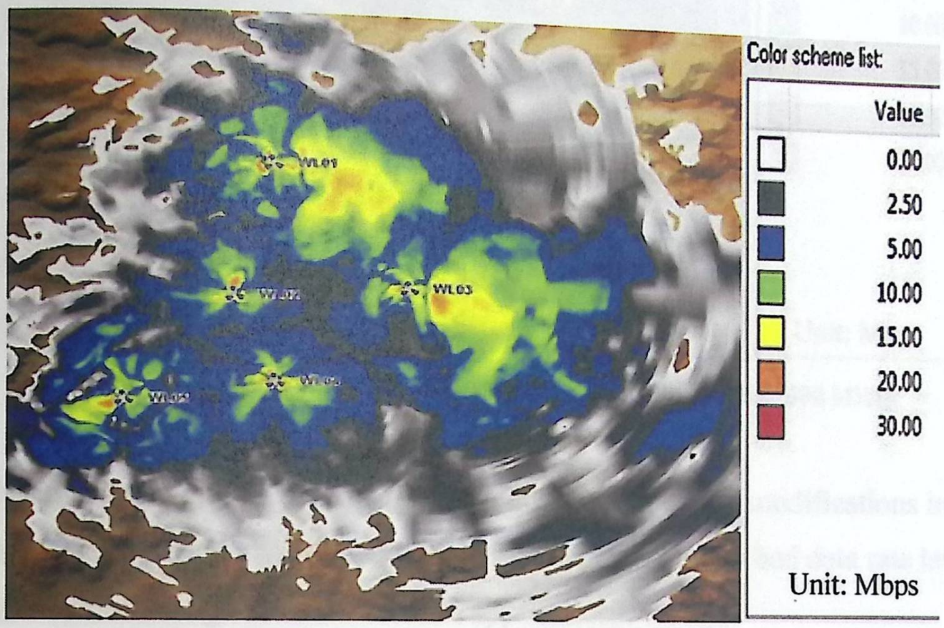


Figure 3.84. Downlink average data rate layer before modifications(1800 MHz).

This was the first view of the downlink average data rate layer before any modifications on the sites. Only two sites were providing a nearly good data rate for small area. The rest of the sites were bad data rate providers.

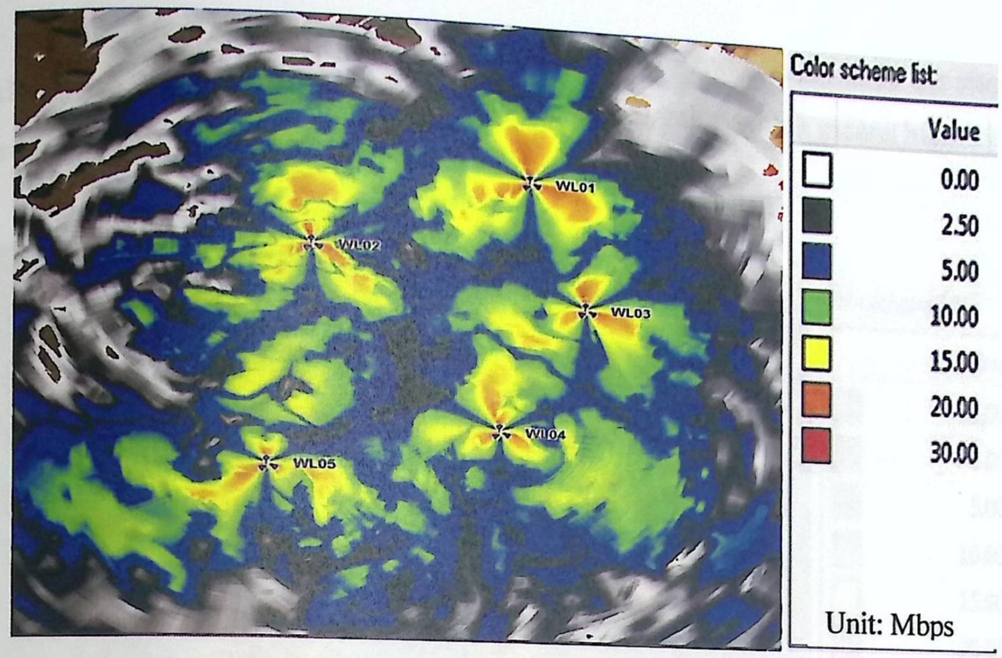


Figure 3.85. Downlink average data rate layer after modifications(1800 MHz).

The improvements on the downlink average data rate after modifications increased the data rate of the sites, but still there was a large area covered by bad data rate level which could be not enough for some mobile applications.

Downlink C/I layer(1800 MHz):

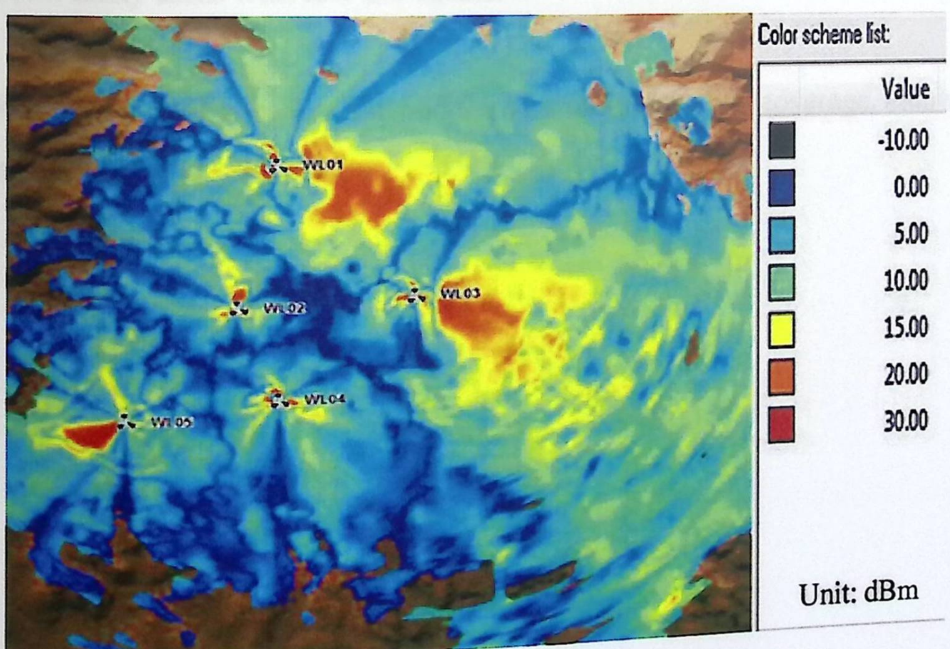


Figure 3.86. Downlink C/I layer before modifications(1800 MHz).

The first view of the downlink C/I layer before any modifications on the sites showed that nearly all the area were covered by low C/I value which means high interference.

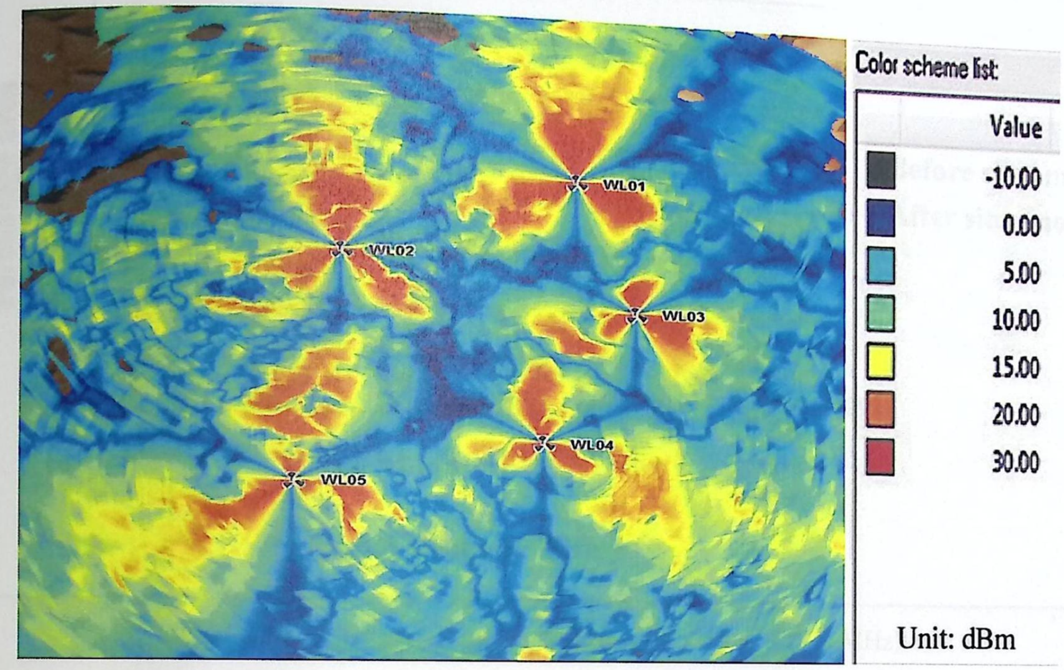


Figure 3.87. Downlink C/I layer after modifications(1800 MHz).

The modifications on the sites increased the C/I value for some small areas. But there was still many areas with low C/I values.

Here is some statistics that showed the improvement in the coverage, data rate and the carrier to interference values:

Best server signal strength layer statistics(1800 MHz):

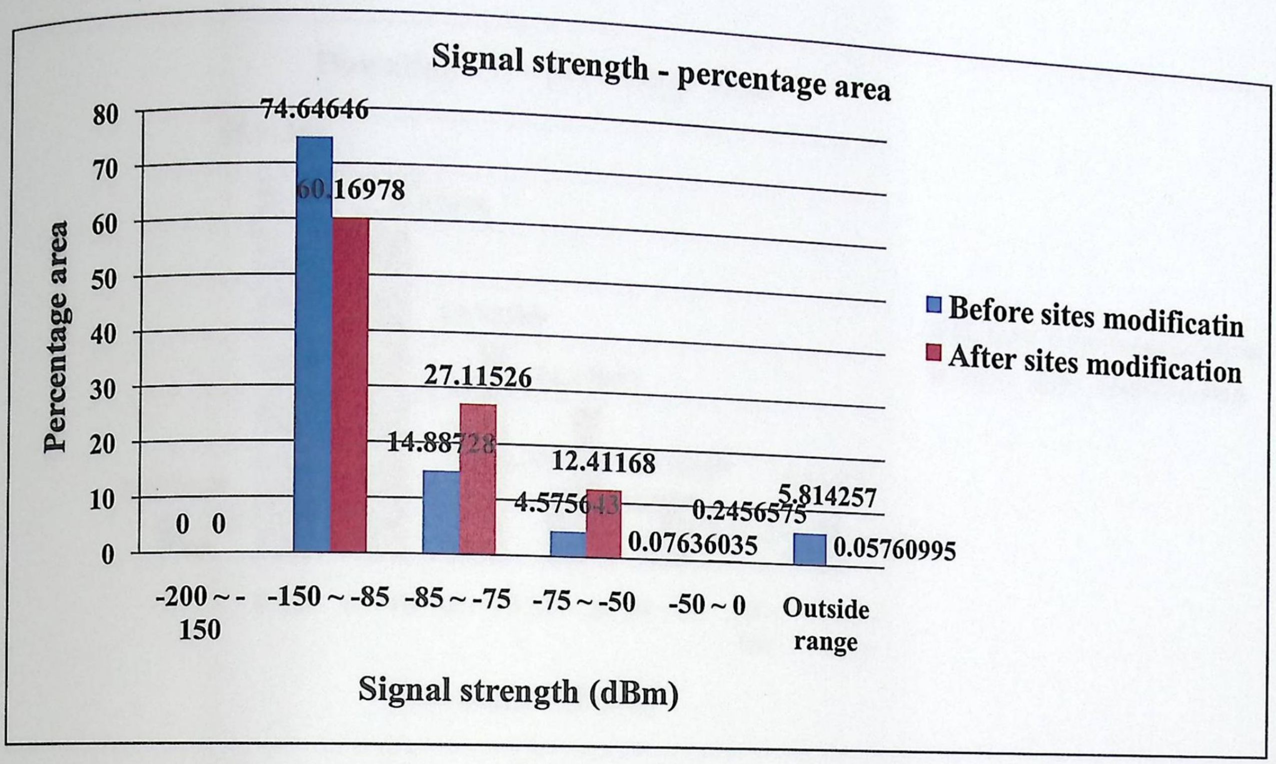


Figure 3.88. Best server signal strength layer statistics(1800 MHz).

Downlink average data rate layer statistics(1800 MHz):

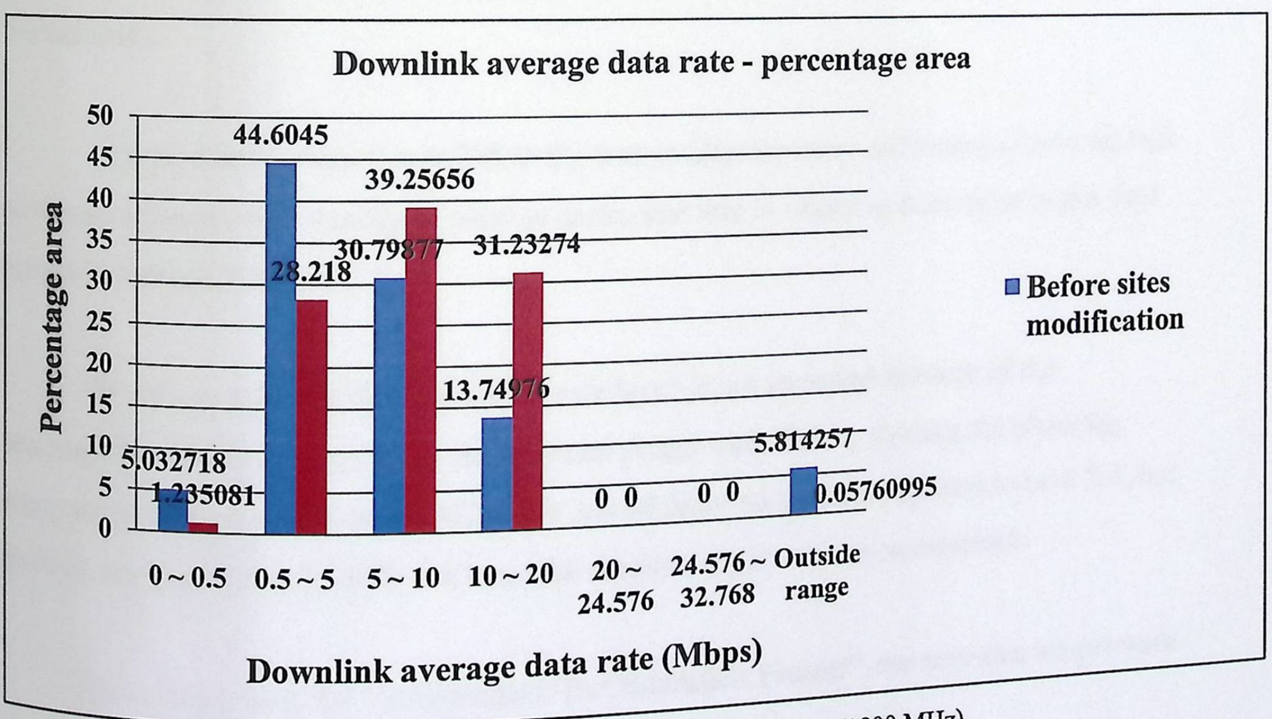


Figure 3.89. Downlink average data rate layer statistics(1800 MHz).

Downlink C/I layer statistics(1800 MHz):

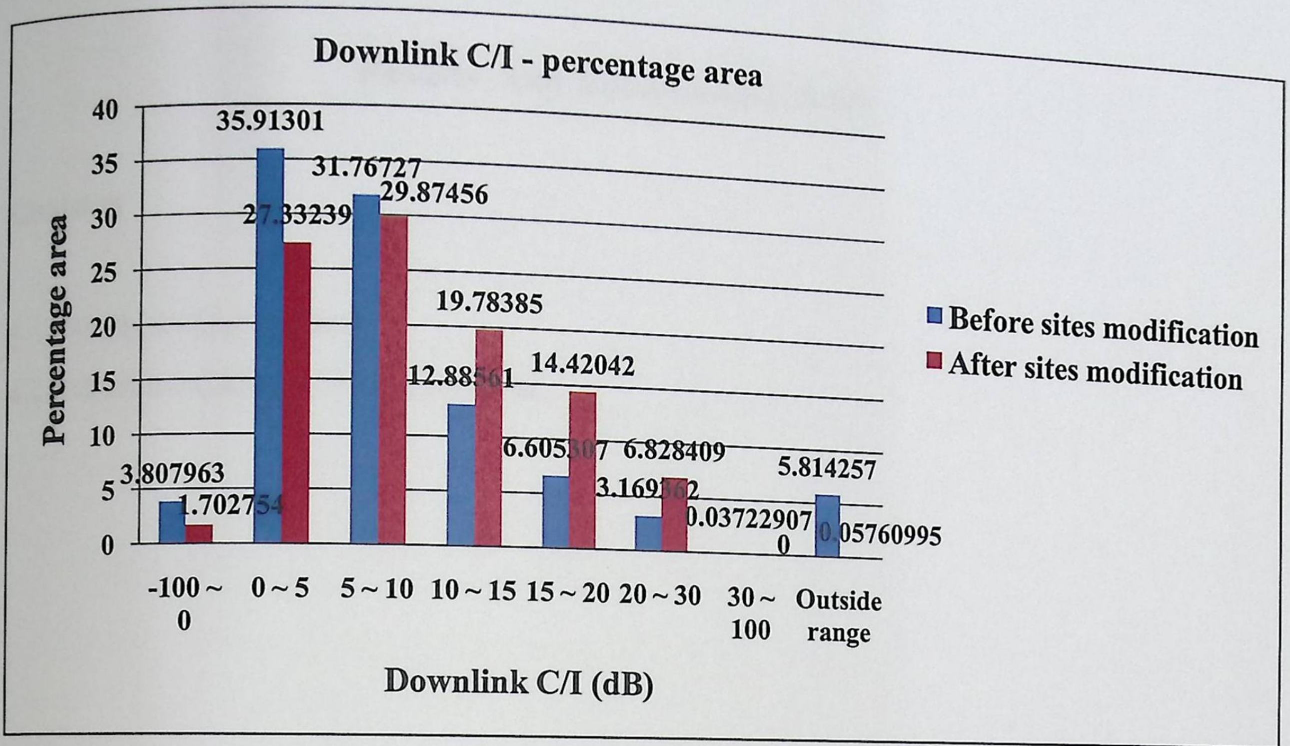


Figure 3.90. Downlink C/I layer statistics(1800 MHz).

All the previous results in WiMAX and LTE planning showed that the achieved modifications were not enough to improve the coverage, capacity and quality of service for the network.

One an other solution was left to try was to allocate more additional sites in the bad coverage, capacity and quality of service areas, and this is what has been done in the final results in section 3.4. and 3.5.

In section 3.4., the downlink data rate layer is not included because of the unacceptable results we get from the Mentum planet tool. Before starting the planning, some parameters were adjusted. MIMO is one of these parameters adjusted to be 4 X 4, but the tool worked as it is MIMO 1 X1; so the results we get was not as expected.

In contrast with the “Introduction To Graduation Project”, the statistics we get were not logical; so they were excluded also from section 3.4.

Chapter 4

Results And Recommendations

Contents

4.1.Results and conclusion

Now at the end of this project, we have a plan for Hebron City for both WiMAX and LTE technologies. This plan performed using Jawwal Mentum Planet simulation tool. This simulation tool shows the terrains of the city, this helps us to choose the appropriate location for the site such that the terrains do not affect the signal strength negatively. The plan performed on three frequencies for each technology. The number of sites is not fixed, it differs according to the used frequency. One of the important points that had been taken into consideration is to achieve a good coverage and QoS for all the region using a minimum number of sites.

Through carrying out the plan, there was a sample of sites that provided a very weak signal. Many attempts were done to improve the signal strength, but the sites did not response to any modifications. So the field survey were needed to determine the exact problem of these sites. After the field survey we can determine the most efficient modifications that must be done for the sites. In this project, the filed survey was performed on two sites in two different regions, the relocation of the site was the most appropriate modification in both regions

Depending on the carried out plan, a comparison between WiMAX and LTE was concluded. This comparison based on core points. The number of sites, coverage (signal strength) and QoS (interference) are the most important three points the comparison based on. The following table shows the comparison:

Table 4.1 Comparison between WiMAX and LTE.

Point	WiMAX						LTE		
Duplexing technique	TDD			FDD			TDD		
Frequency	2300 MHz	2500 MHz	3500 MHz	2300 MHz	2500 MHz	3500 MHz	1800 MHz	2100 MHz	2600 MHz
Number of sites	80 Site	86 Site	96 Site	86 Site	86 Site	96 Site	84 Site	94 Site	104 Site
Channel bandwidth	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	5 MHz	10 MHz	10 MHz	10 MHz
Modulation	PSK+ QAM	PSK+ QAM	PSK+ QAM	PSK+ QAM	PSK+ QAM	PSK+ QAM	PSK+ QAM	PSK+ QAM	PSK+ QAM
Antenna radiated power	47 dBm	47 dBm	47 dBm	47 dBm	47 dBm	47 dBm	47 dBm	47 dBm	47 dBm
Antenna height	25 m	25 m	25 m	25 m	25 m	25 m	25 m	25 m	25 m
Coverage (Signal strength)	(-75.01 ~ -75) dB	-60.19 dB	-60.19 dB	(-85 ~ -75) dB	(-85 ~ -75) dB	(-75 ~ -60.19) dB	(-75.01 ~ -75) dB	(-75 ~ -60.19) dB	-60.19 dB
Interference . (C/I)	Average 0 dBm	Average (0 ~ 5) dBm	Average (15 ~ 20) dBm	Average (-2 ~ 0) dBm	Average (-2 ~ 0) dBm	Average (-2 ~ 0) dBm	Average (0 ~5) dBm	Average (5 ~ 10) dBm	Average (20~30) dBm

1. Number of sites.

From table 4.1, we can realize that WiMAX needs less increasing in number of sites than LTE, although the difference between any two frequencies of the WiMAX is larger than that difference in LTE. For example, in WiMAX when we move from 2500 MHz to 3500 MHz (i.e 1000 MHz difference), 10 additional sites were needed to overcome the decreasing in the coverage and the carrier to interference value. Whereas in LTE when we move from 2100 MHz to 2600 MHz (i.e 500 MHz difference, which is less than 1000 MHz difference in WiMAX), 10 additional sites were needed also.

2. Coverage (signal strength).

From table 4.1, we can note from the comparison between WiMAX TDD and LTE that WiMAX TDD provides most of the area with a higher signal strength value (- 60.19 dB average) than LTE does (-75 ~ -60.19 dB). whereas the comparison shows that LTE could provide higher signal strength value (-75.01 ~ -75 dB) than WiMAX FDD (-85 ~ -75 dB). Generally speaking, WiMAX TDD is commonly used all over the world than WiMAX FDD, so we can say that WiMAX is better than LTE in terms of coverage.

3. QoS (interference).

From table 4.1, we can conclude that LTE provides higher carrier to interference value than WiMAX TDD and WiMAX FDD. Although LTE provides higher carrier to interference, for some services the value of carrier to interference value of WiMAX could be enough.

Conclusion:

This project raises the advantages and the disadvantages of both technologies (WiMAX and LTE). WiMAX has the advantage of good coverage, while LTE has a good QoS. This gives the provider the opportunity to choose the most effective technology for the network. There are many points must be taken into consideration before choosing the technology. Number of users in the region, their needs, terrains of the region, the existed infrastructure, and the cost of establishing the network are the most important points.

4.2.Recommendations for future works

Here there are some recommended points for future work:

1. Expand the plan to include all Palestine.
2. Using another simulation tool that take buildings and other clutter into consideration.
3. Study LTE and WiMAX in terms of capacity (i.e. data rate).
4. Study the effect of different order of MIMO.

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Appendix

Table 2.1. WiMAX Different Versions

Specification	Year of Ratification	Description
802.16	2001	MAC and PHY definition for fixed broadband wireless access in the 10 – 66 GHz frequency band.
802.16a	2003	Amendment to the original specification. Contains new PHY definitions for the 2–11GHz frequency bands. Also includes mesh network modes of operation.
802.16c	2002	System profiles for 10 – 66 GHz operations.
802.16d	2004	Contains 802.16, 802.16a and various MAC enhancements. Commonly referred to as 802.16-2004. Considered the base 802.16 fixed broadband wireless specification.
802.16e	2006	Amendment to the 802.16d specification to provide explicit support for mobility. Incorporates WiBRO. Commonly referred to as 802.16-2005. Considered the base 802.16 mobile broadband wireless specification.
802.16f	2005	802.16 management information base.
802.16g	In progress	Network management(management plane control procedure).
802.16h	In progress	Coexistence in licensed exempt frequency bands.
802.16i	In progress	Mobile management information base.
802.16j	In progress	Multi hop relay specification.
802.16k	In progress	802.16 MAC layer bridging.
WiBRO		Korean wireless broadband standard

		incorporated into the 802.16e (802.16-2005) standard.

Reference: [(9),page19,table1.1,"Summary of Various 802.16 Technology Specifications"]

Table 2.2. Frequency Bands Of WiMAX Different Versions

Standard	Frequency range	Feature
IEEE 802.16a	Having licensed Exempt frequencies (2-11 GHz).	At lower frequencies the signals can penetrate barriers and do not require line of sight between transmitter and receiver.
IEEE 802.16b	5-6 GHz.	Provides high quality of service for transmission of real time voice and video.
IEEE 802.16c	10-66 GHz	This encourages more consistent implementation and more interoperability.
IEEE 802.16d	2-11 GHz fixed	Adds support to 802.16a for indoor customer premise equipment. This standard combines the PHY layer and MAC layer, ensuring a uniform base for all WiMAX stations. It uses mounted antenna at the subscriber site. Uses OFDMA for optimization of wireless data services.
IEEE 802.16e	2-6 GHz portable	Adds support for mobility. Using OFDMA, it divides the carriers into multiple subcarriers. It goes a step further by then grouping multiple subcarriers into subchannels.

Reference:.[(9),page54,table3.2,"WiMAX IEEE 802.16"]

Table 2.3. Differences Between LTE And WiMAX

Aspect	3GPP-LTE	Mobile WiMAX (IEEE 802.16e)
Legacy	GSM/GPRS/EDGE/UMTS/HSPA	IEEE 802.16a through d
Access technology: Download (DL) Uplink (UL)	 OFDMA SC-FDMA	 OFDMA OFDMA
Radio Access Modes	TDD and FDD	TDD and FDD
Frequency Band	Existing (800,900,1800,1900 MHz) and new frequency bands (Range 800 MHz - 2.62 GHz)	NLOS: 2-11 GHz
Peak Data rate DL UL	 100 to 326.4 Mbps 50 to 86.4 Mbps	 75 Mbps 25 Mbps

Reference: :[(29),page46,table7,"Highlights of LTE and WiMAX comparison"]

Table 2.3. Differences Between LTE And WiMAX

Aspect	3GPP-LTE	Mobile WiMAX (IEEE 802.16e)
Legacy	GSM/GPRS/EDGE/UMTS/HSPA	IEEE 802.16a through d
Access technology: Download (DL) Uplink (UL)	 OFDMA SC-FDMA	 OFDMA OFDMA
Radio Access Modes	TDD and FDD	TDD and FDD
Frequency Band	Existing (800,900,1800,1900 MHz) and new frequency bands (Range 800 MHz - 2.62 GHz)	NLOS: 2-11 GHz
Peak Data rate DL UL	 100 to 326.4 Mbps 50 to 86.4 Mbps	 75 Mbps 25 Mbps

Reference: :[(29),page46,table7,"Highlights of LTE and WiMAX comparison"]